DOE/ID/13367

Development of Advanced Sensor Technologies for the United States Glass Industry

Final Report – 07/20/1995 – 08/19/1999

B. L. Conner
C. Cannon

December 1999

Work Performed Under Contract No. DE-FC07-95ID13367

For
U.S. Department of Energy
Assistant Secretary for
Energy Efficiency and Renewable Energy
Washington, DC

By
AccuTru International Corporation
Kingwood, TX

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Prepared for
U.S. Department of Energy
Idaho Operations Office, Idaho Falls, ID
Washington, D.C.

Prepared by
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Kingwood, Texas
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1.0 Executive Summary

AccuTru International, in cooperation with representatives of the four primary segments of the glass industry, with support from the Department of Energy, undertook a project to significantly improve temperature measurement in glass melters. The impetus for this was the desire to reduce energy usage through improved process control. AccuTru conducted a study of the needs for improvement of temperature measurement in the glass industry. The primary need, according to the survey, was to find a way to identify in situ decalibration in platinum-platinum/platinum-rhodium thermocouples. Additional improvements desired included improved range, accuracy and repeatability.

AccuTru conducted a series of tests designed to produce a new sensor technology for the glass industry.. Testing determined that a new type of protective sheath would be required to move forward on that path. As a result, AccuTru begin to study advanced sheath materials, and preliminary results show significant improvements in this area. In cooperation with Corning, Incorporated, the University of Missouri-Rolla ceramics department conducted a in-situ test of several alternative sheath materials, one of which shows significant promise. However, due to the time limitations of the study, further development of the material was not possible. However, AccuTru is continuing to fund the research and development of this material. In addition, further conversations with representatives of the glass industry caused us to seek approval for a modification to the project to focus the primary efforts on development of a self-verfying sensor system. This modification was approved by the Deparment of Enxery, with the approval of a second phase of the project, with the focus on improvements to the self-verifying feature of the sensor and the accompanying electronics needed to support the new sensor design.

Bench tests confirmed the feasibility of the self-verifying sensor technology. Two sensors were constructed using this new design. Arrangements were made to install the sensors in two tanks at a Corning facility. One system was installed in an oxy/fuel furnace and the other in an air/fuel furnace. Using a proprietary alumina sheath technology, Corning estimated the sensors would last approximately 90 days in the furnace locations selected, based on previous experience with alumina sheathed thermocouples. The objective was to use materials that would begin to degrade in a reasonable time so that we could test and validate the self-verifying features of the self-verifying sensor system.

Locations of the sensors were between two existing sensors that reported data to the control room. By comparing the readouts of the two adjacent sensors with the self-verifying sensor, it was possible to extrapolate the performance of the self-verifying sensor. In addition, our internal data analysis methodology was able to validate the readings in comparison to the data reported by Corning.

The performance of the sensors exceeded expectations. As of January 15,2000, the sensors were both performing within standard limits of error, well beyond the projected life for this test. The plant test identified several issues that needed to be addressed. One of these is the need to further enhance the electronics component's resistance to plant noise, and second, the need for additional research on the development of enhanced protective sheath materials to replace the platinum currently used.

AccuTru is continuing the development of advanced protective sheath materials as replacement for platinum probe protection. Once these new materials are developed, it will be possible to increase the upper temperature limits of the self-verifying probes.

Accomplishments include the demonstration of the validation feature of the self-verifying sensor system. In addition, the project demonstrated the accuracy of the SVS system versus the calculated test port temperature (TPT). Precise repeatability tests in melter service are not possible due to absence of a traceable standard. Laboratory testing demonstrated repeatability.

2.0 Introduction, Review of Phase I, Project and Phase II Objectives, and Phase II Tasks

2.1 Phase I Summary

The U.S. Department of Energy has identified seven major industry groups as high energy consuming industries. The DOE decided to assist these industries in reducing their energy consumption, thereby reducing pollution and increasing efficiencies that will allow for an improved competitive position in the world market. The U.S. glass industry is one of the seven industries consuming approximately 300.0 x 10^{12} BTUs of energy annually. One area identified by the industry and DOE where improvement will make a substantial contribution to the DOE's objectives is improved temperature measurement in the melting and delivery systems of the glass making process.

The Department of Energy became aware of conversations between AccuTru and Corning, Incorporated concerning solutions to temperature measurement problems in the melting and forehearth areas and granted an award to AccuTru for research, development, and demonstration of an advanced temperature sensor for the entire glass industry.

The initial statement of work was prepared using the best data AccuTru could secure from the DOE, available public literature, and limited access to the industry (due to proprietary concerns of the companies.) As the project proceeded, a better understanding of the glass industry was obtained, regarding their real needs, wants, and future desires.

AccuTru conducted a needs analysis survey among employees of the industry participants (Corning Incorporated, Libbey-Owens-Ford, Owens-Corning, and Anchor Glass Container) and developed a very close working relationship with plant furnace operators, systems engineers, technicians, and managers. The information gained as the project proceeded made it obvious that, in order to make a substantial impact on the glass industry's temperature measurement problems, more than an improved glass sensor was needed.

The single greatest problem, according to the survey, and confirmed in follow-up discussions, is the inability to identify in situ decalibration (drift). Any advanced sensor that is more rugged and reliable still has the uncertainty of drift and, therefore, is only marginally more useful than what is being used by the industry today.

For this project to be considered a success by the glass industry, and to meet the original desires of DOE, the project required the development of an advanced sensor system that includes:

A more rugged, reliable sensor,

- High quality inner protective sheath,

Improved data transmission that is hardened to the environment of the melt tank surroundings,

A system that reduces or eliminates in situ decalibration (drift),

- An improved outer protection sheath.

During Phase I of the project, AccuTru pursued the advanced sensor development identified in the original "Statement of Objectives" and, at the same time, with concurrence of the Department of Energy, shifted resources to address the other problems identified by industry. All or most of these problems needed to be resolved in order to make a major step forward in temperature measurement in the glass industry. Through Phase I, testing determined the feasibility and preliminary performance characteristics that met or exceeded the project criteria.

Temperature System Requirements

Smart Temperature Monitoring System

Although not initially considered at the inception of the project, the capability to determine the magnitude of drift, or decalibration, in a primary tank measurement system was determined, by the surveys, to provide the principal benefit to the glass industry. Further analysis determined that the ability to identify, and within limits, correct for drift would be a significant step forward in the measurement of temperature using thermocouples.

Improved Range, Accuracy, and Repeatability

Industry responses indicated a consensus of performance parameters requested by the U.S. glass industry included:

Increased Upper Operating Range:

An improved operating range to 1700°C.

Improved Accuracy:

Better accuracy, especially over the upper operating ranges, to within +/- 0.5% over the life of the sensor.

Improved Repeatability:

Better capability to return to a previously established temperature setting, especially over the upper operating ranges, to within +/- 0.1% or better.

Improved Lifetime:

Better sensor lifetimes were determined to be important to the U.S. glass industry. Sensor replacement in primary melt tank applications is especially difficult. In many cases, if a sensor fails, it cannot be replaced until the end of a campaign. If there are multiple failures, this creates a significant control problem. A consensus of industry participants is for a better sensor life expectancy of between five and ten years.

Ease of Replacement:

An important aspect of the new sensor design was determined to be the ease of replacement. When sensors are directly inserted into the melt region, a sensor that can be replaced without disturbing the outer protective sheath was determined to offer high value in the reduction of maintenance costs.

Other requirements:

Thermal shock resistance - the ability to withstand fracture stresses imposed by sudden insertion into the primary melt tank interior during sensor replacement; Vibration - Immunity to the wide variety of frequency and amplitude vibration spectrums that exist in modern glass manufacturing plants; Common Mode Noise Rejection - 600 VAC; Electrical Leads: System must accommodate up to 150 foot lengths of lead from the sensor to the remote electronics unit and 400 foot lead lengths between the remote electronics unit and the control room electronics; Signal Conditioning Electronics - The criteria for the electronics package was an operating temperature of up to 70°C, with a dimensional size of 5" x 5" x 5"; Primary tank insertion depth of the sensor is in a range from 0.5" to 10".

Phase I Conclusions and Recommendations, and Objectives of Phase II

Through Phase I the project demonstrated in the laboratory tests that it is possible to address four of the five problem areas and that, with the assistance of the University of Missouri-Rolla's materials group, it may be possible to address the fifth problem, the outer protective thimble. It has been demonstrated in the laboratory that it is possible to solve the major identified problem, the inability to identify in situ decalibration (drift).

Based on the performance of the test sensors, it was recommended that the Phase II "Statement of Objectives" be modified to add the following tasks:

Develop and test hardware and software unique to the glass industry that will capture the multiple signals generated by the Advanced Sensor developed in Phase I. The new hardware will analyze the data and report both temperature and confidence level indications that the sensor is reporting data that is within special limits of error, standard limits of error, or limits established by the user.

The second task added to the project in phase II was the development of an advanced outer protective sheath material for glass sensors.

Overview of Advanced Temperature Measurement System for the U.S. Glass Industry Melt Tanks and Delivery System

Introduction and Project Objectives - Phase II

There are five primary objectives of this project. They are 1) A more rugged, reliable sensor, 2) High quality inner protective sheath, 3) Improved data transmission that is hardened to the environment of the melt tank surrounding, 4) A sensor for the glass industry that reduces or eliminates in situ decalibration, and 5) An improved outer protection sheath. Phase I made significant progress in four of the five areas. Testing for improved outer protection sheath was part of Phase II. During Phase II additional improvements were made in objectives 1 through 4 and advancements were identified in the outer protection sheath (thimble), objective 5.

As Phase II developed, based on host site requirements, economic considerations, and new approaches, it was prudent to modify some of the tactical objectives of the original project. This was accomplished with the approval of the DOE Technical Monitor, AccuTru's PI and the host site project manager. As an example, it was decided to reduce the number of test melters from four to two. One oxy/fuel and one air/fuel melter were used in the Phase II evaluation. It was decided that the test data from this combination of crown regions of the melters would be the most cost-effective method without reducing the validity of the data or the quality of the project.

Phase II Objectives

With the completion of the development and testing conducted in Phase I of the project, the objectives of Phase II were to test and demonstrate sensor performance in a typical manufacturing environment. The following are the specific objectives for Phase II:

- Demonstrate the verification function (The SVS System notifies the operator when the system starts to become impaired),
- Demonstrate accuracy of the SVS System as compared to the neighboring operational sensors, and
- Demonstrate the life of SVS System as compared with other temperature measurement devices in similar protection wells (thimbles).

2.4 Phase II Tasks

Original	Additions/Deletions	Changes
Task 2.1 Prototype Sensor Modifications	• Task 2.11 Develop improved Microprocessor Based Electronic Hardware and Software	
• Sensor Modifications	• Task 2.12 Develop an Advanced Outer Protective Sheath	
• Electronics Modifications		
• Checkout Testing		
Task 2.2 Laboratory Test Verifications		
• Verification of performance		
• Test plan reviewed with DOE		
• Host site testing agreements		
• Copy of agreement to DOE		
• Four sites	• ~~Four sites~~	• Two melters, one air/fuel and one oxy/fuel
• Installation drawings		
• Single line electrical		
• Process instrumentation and control		

Original	Additions/Deletions	Changes
• Mechanical and electrical interface		
Task 2.4 Host Site Testing		
• Test plan reviewed with DOE		
• Test matrix		
• Length of test 3 to 4 weeks	• ~~Length of test 3 to 4 weeks~~	• Length of test - 3 months
• Baseline data		
• Location of probes		
• Temperature reference system		
• Installation/passive mode		
• Start-up Check-out		
• Host site communication		
• Data collection/evaluation		
• On-going modifications		
• Postmortem	• ~~Postmortem~~	• Continue to failure
• Comparison to existing temperature measurement system		
• Feedback to host site		

Original	Additions/Deletions	Changes
Task 2.5 Management and Reporting • Provide a final report • Functional and performance specification of the sensor • Installation • Test • Cost effectiveness • Model development and use • Commercialization plan • Paper to professional society		

3.0 Test Devices Preparation and Laboratory Test Verification

3.1 Modification of prototype sensors

Two modifications were required in the initial sensor design. The first required a redesign of the sensor's inner protective sheath due to continual failure of the ceramic protective sheath material in the prototype sensors that were tested.

The initial design of the glass sensors called for a leak-tight ceramic tube. The literature on ceramic tubes and information obtained from manufactures of ceramic protection tubes indicated that the ceramics would remain leak-tight at 1750°C.

AccuTru tested seven sets of ceramic protection tubes to 1750°C and all failed to maintain integrity within a period of eight hours after the furnace was raised to 1750°C. Initially, we believed that the failure was the result of improper sealing of the sensor around the thermoelements at the cold end of the sensor. However, extensive testing and monitoring using helium leak detecting equipment determined that the seals maintained their integrity, but the failures were ascertained as occurring at the tip of the sensor, in the region where the end of the tube was closed during manufacture. These tests determined that the literature and information provided by the manufacturers regarding leakage of the ceramic sheath at temperature could not be validated and that, when heated to the temperatures at which the sensor was designed to operate, the ceramic sheaths, regardless of manufacturer, did not maintain integrity .

A second modification of the sensor design was required at the request of Corning, Incorporated. After extensive discussions with melt directors and other members of the Corning technical staff, Corning asked that the sensor be redesigned to eliminate some of the metals used in the prototype sensor. There was concern that if one of the sensor protective sheaths failed, and the internal materials of the sensor were exposed to the melt furnace environment, the metals could separate and fall into the melt, causing serious problems, which could result in a substantial loss of glass due to contamination.

A thorough analysis of alternative thermoelement configurations was conducted. It was determined, through this assessment, that all of the thermal materials from the original design would need to be changed in order to preserve compatibility and meet the requirements of the Corning technical staff. Thus a complete reconfiguration of the sensor elements was required, replacing the initial configuration of sensor elements with different thermoelements.

3.2 Modification of the electronics

As the development of the AccuTru's non-glass SVS concept was refined, it became apparent that there could be significant gains made in the performance of the glass system if we migrated from a mechanical/electrical - analog/digital system that was developed for the glass sensor, to an electronic digital remote electronics unit. Working with one of AccuTru's alliance partners, Scientific Microsystems of Tombal, Texas, a new printed circuit board was developed that could replace the prototype electro-mechanical system.

The new microprocessor based circuit board provided improved accuracy, provided for enhanced logic capabilities, and increased the frequency of sensor interrogations, thus providing improved response time. The initial instrumentation was driven by the SVS software, from the data terminal, which activated the data terminal to query each sensor/electronics module on the loop for raw data. Once the data was collected, the data terminal software performed the analytical work required to calculate and display a temperature readout, indication of sensor's health, and validate the confidence level of the temperature readout.

The new printed circuit board contains its own CPU (central processing unit). It is a state of the art smart transmitter performing all of the calculations and analysis for the attached sensor, and making available the validated sensor output and health to any connected electronic system. With this new enhanced system, the only function of the data terminal is to query the boards and display the data on the screen. This new methodology allows for very fast response time, and prevents total system failure because each sensor and its transmitter operates independently of the data terminal. With the implementation of this new hardware, data from each sensor is processed 2-4 times per second.

In addition, the new board provides a digital 24 bit resolution with a 16 bit 4-20 milliamp output, or other output protocols for direct output of the SVS data into a DCS or PLC system when requested. Along with the addition of the temperature reading, the system provides for periodic transmission of the sensor health. A DCS system can be set up to display sensor health, along with output temperature. This data can be integrated into an existing system without the need for an operator to monitor an additional CRT.

A half-duplex data link using a serial interface buss provides communications between the microprocessor based electronics unit and the data terminal for both configuration and monitoring of sensor output. Since signal processing occurs on the individual board, there are no limits to the number of sensors that can be handled by the data terminal.

The microprocessor based electronics module is configurable to the user's needs. It collects data from the sensor and can apply selected smoothing and data filtering according to the data collection parameters established by the user and downloaded to the board at installation.

3.2.1 Revisions to Software

With the development of the new microprocessor based electronics modules, it was necessary to create a new software package. The initial software was rewritten to provide two new software packages, one for the data terminal, and a second for downloading to the electronics board. Because the electronics modules perform the mathematical and logic calculations that formerly were managed by the data terminal, new software was required that could be downloaded to the board, enabling these functions to be carried out on the board instead of the data terminal.

The data terminal software was rewritten to eliminate all of the mathematical and logic calculations that are now performed on the remote electronics board, and enhanced to provide rapid data collection and display. In addition, a module was added to the software to enable users to download the operational software to the microprocessor boards.

Figures 3.1 is a high level software flowchart used to prepare the necessary algorithms used to process incoming data from the sensor. Figure 3.2, is a high level flow chart used to process data that is used to validate the temperature readout. Figure 3.3 is a high level flowchart used for the algorithms that determine the condition of the sensor. A confidence level is also computed each time the sensor is evaluated. In general, these functions were not changed from the initial electronics components, except that the code was rewritten and modified to take into consideration some of the advanced features of the new remote electronics board.

3.3 Bench top testing, verification, calibration and final checkout

Once it was agreed to modify the design of the sensor, a new set of prototype sensors were built. At the completion of the build, a set of three sensors was tested to 1750°C in a bench test. The initial test determined that the sensors performed as designed in the laboratory environment. As a part of the bench top testing, it was necessary to develop new data sets to convert sensor output into temperatures. These tables were then installed in the SVS software. Once the new data sets were installed, a second abbreviated test was performed on the sensors to be sent to Corning to check their performance against a NIST traceable standard. With the new data sets, the sensors performed better than the specified limits of accuracy in the laboratory test furnace. These limits, as defined for the Corning Test were chosen to be Standard Limits of error for a Type "S" and Type "R" Sensors of .25% and .5% for a Type "B" sensor in the expected temperature range.

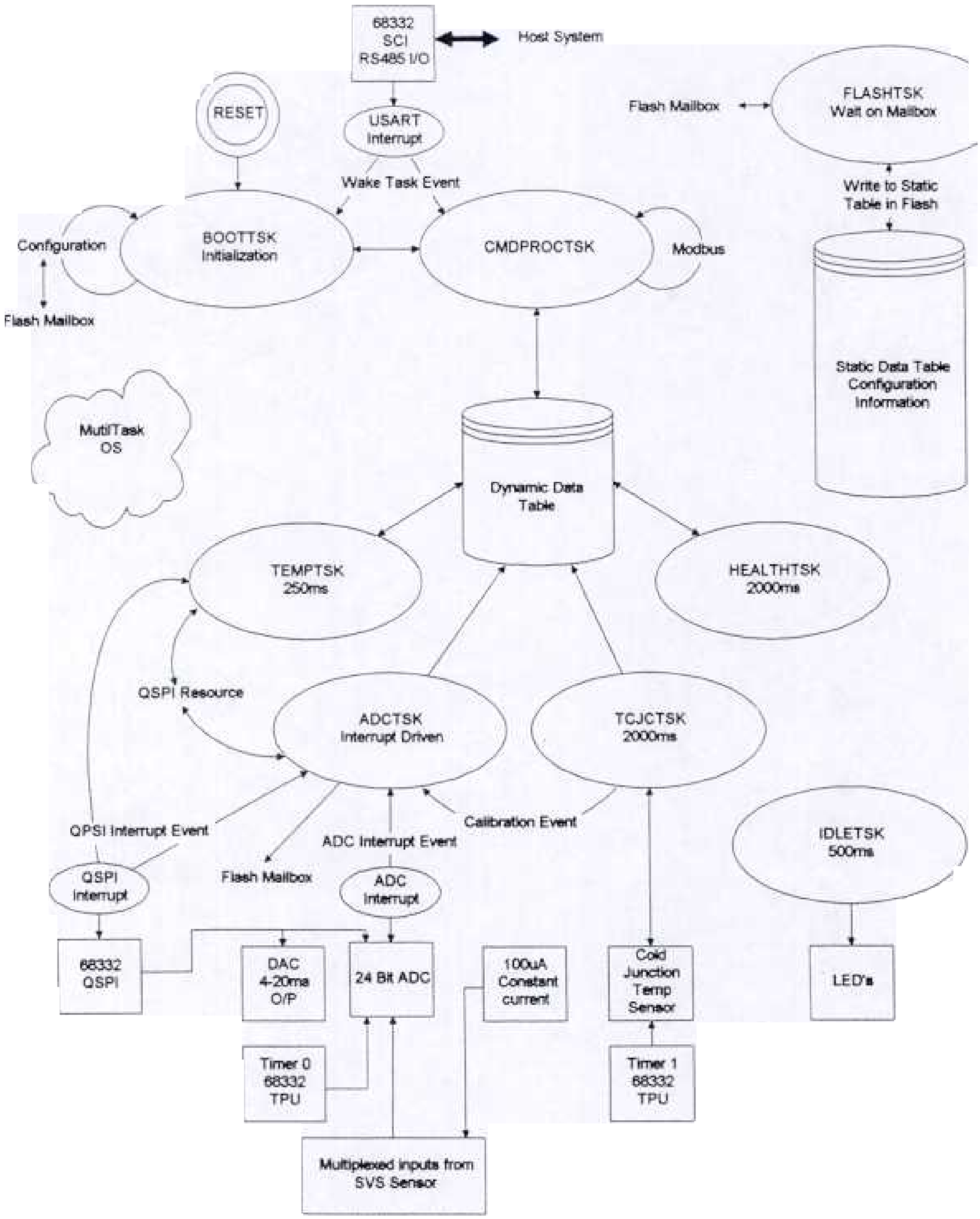


FIGURE 3.2 High level software flowchart identifying major algorithms used to validate sensor temperature.

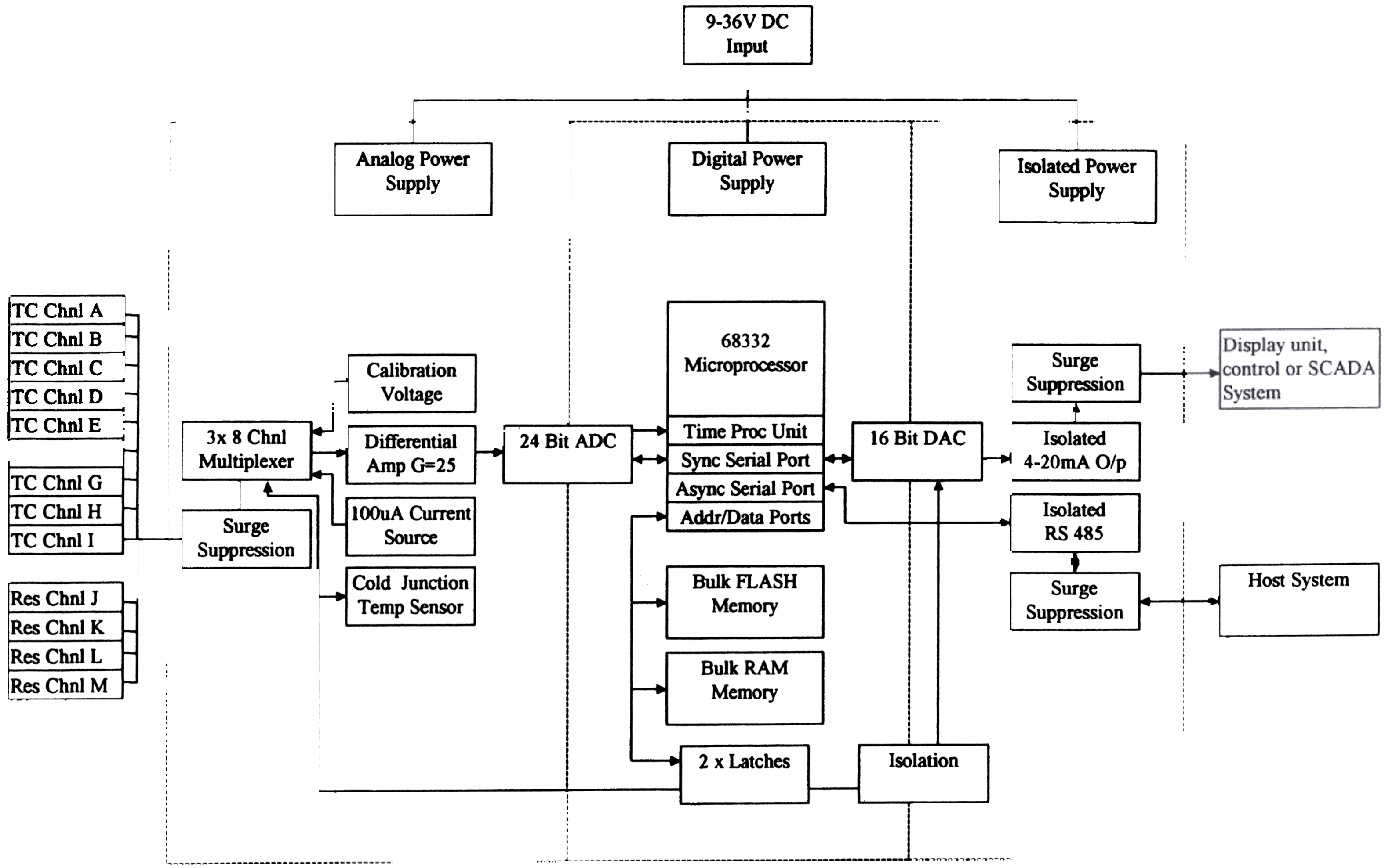


FIGURE 3.1 High level software flowchart identifying major algorithms used to process SVS sensor data

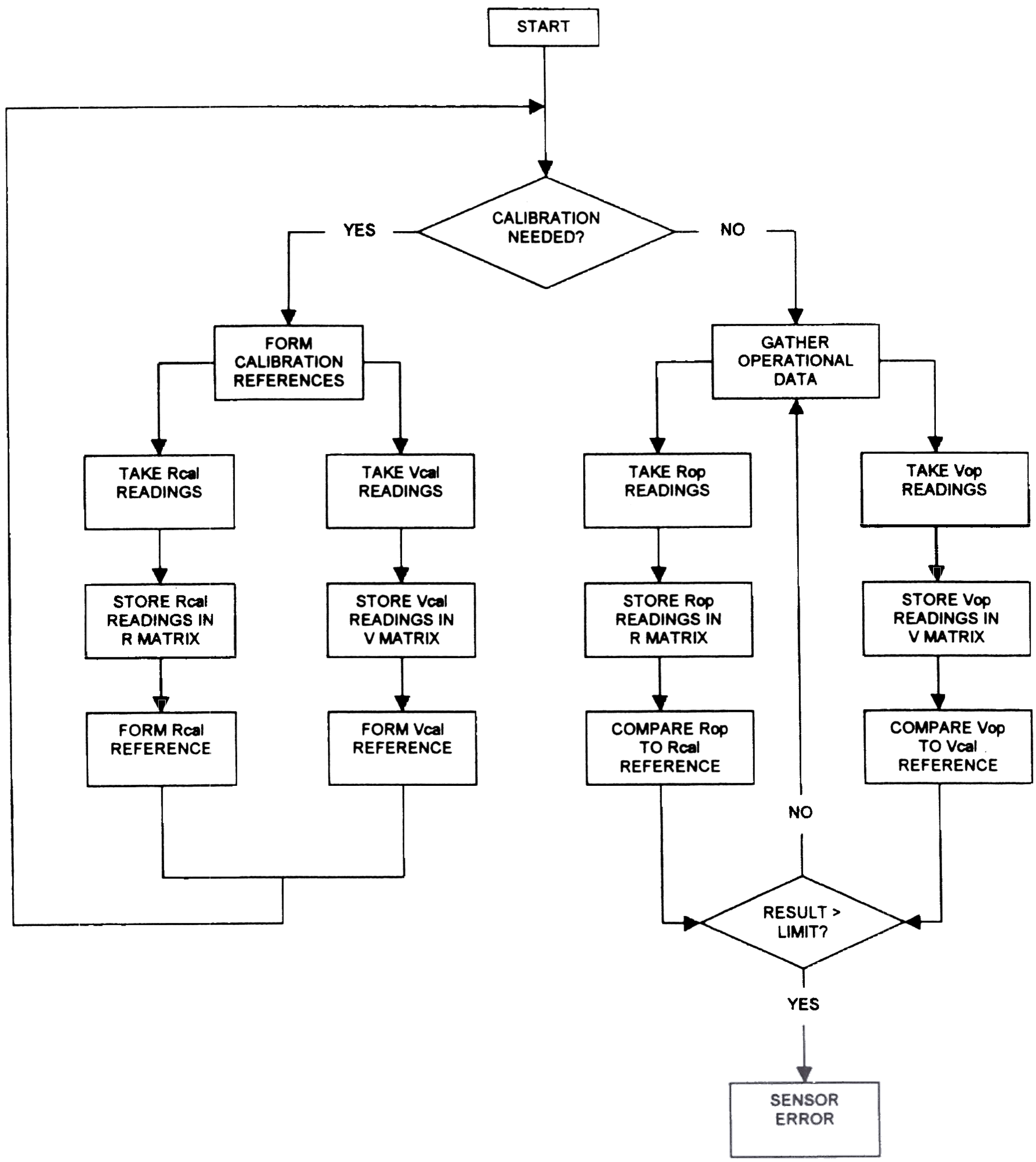


FIGURE 3.3 High level software flowchart identifying major algorithms used to assess sensor condition.

3.4 Sheath test results

The primary method of sensor protection in the glass industry is a platinum sheath. The use of platinum is problematic in that, due to the corrosive nature of the tank environment, the sheaths provided limited lifetime and sensor reliability. In addition, the platinum inventory required, and loss of material is a considerable expense to some of the the companies involved.

One of the objectives of the project was to determine if a better candidate sheath material was available. The objectives included improved corrosion resistance, improved life, improved high temperature creep resistance, and a design that would allow simple replacement of the internal sensor if needed.

Literature and data relating to candidate sheath materials for use in primary melt tank environments was reviewed. Attention was given to the nature of the corrosive attack on the materials, and design and processing parameters that are known to extend the life of these materials in melt tank environments.

A total of eight materials were selected for evaluation testing. Some of the materials have the same chemical composition, but were fabricated by differing processing methods. The primary requirements were:

> Material is known or expected to be resistant to corrosion from both the crown and melt regions of primary melt tank environments.
>
> Material is known to possess high creep stress resistance at melt temperatures.
>
> Material can meet manufacturability requirements.
>
> Material is readily available.
>
> Material is cost effective.
>
> Material meets requirements for fabrication into an outer protective sheath for the advanced temperature sensor.
>
> Materials should be compatible with molten glass from a defect standpoint.

AccuTru, and its consulting associate, Dr. Jeff Smith, University of Missori - Rolla, in cooperation with Corning, Incorporated, conducted a series of tests and evaluations on thermocouple sheath materials.

The first was a post-mortem characterization of used thermocouple sheaths. Alumina protective sheaths from four different glass tanks were provided for analysis. Two of the sheaths were from oxy-fuel fired tanks and two were from air-fuel tanks. All of the tanks were used to melt glass with similar type of composition. All four sheath specimens were visibly corroded. The sheaths from the air-fuel tanks had been in place less than 1/2 the time as the sheaths in the oxy-fuel tanks although all sheaths showed similar wear patterns and degradation.

CL (Color Luminesence) microscopy and SEM (Scanning Electron Microscope) analysis indicated that the alumina sheaths reacted with CaO and MgO to form $CaO(Al_2O_3)$ A small amount of $MgAl_2O_4$ was also detected on the sheath. There was evidence of calcium aluminate material across the entire portion of the sheath that was exposed to the process gasses. The formation of the calcium aluminate resulted in a large volume increase in the sheath, opening large cracks along the length of the sheath. These cracks allowed process gasses to attack the exposed platinum thermocouple wires, causing corrosion that failed the thermocouple wires. The formation of the above noted compounds suggest that the corrosion is the result of batch carryover and/or volitization from the melt surface.

3.4.1 Laboratory Corrosion Studies

In addition to alumina, two additional candidate materials were considered. These were yttria and zirconia. A laboratory test was conducted using samples of these two materials along with representative alumina samples. Specimens were suspended above a crucible filled with 50 wt.% flux, 40 wt.% silica, and 10 wt.% CaO. The furnace temperature was raised to 1500 and 1600°C and held for 6 to 24 hours.

SEM characterization of the corroded specimens found that CaO had reacted with the alumina standard material to form the same calcium aluminate compounds observed in the post-mortem study. Some degree of reaction had occurred at all temperatures and hold times. As expected, more corrosion was observed for the higher temperatures and the longer hold times. Neither the yttria nor the zirconia showed signs of reaction during the laboratory corrosion studies.

3.4.2 Industrial Melt Tank Study

Corning, Incorporated provided one of their furnaces to evaluate candidate materials. An oxy-fuel glass tank was selected. The final procedure involved extending candidate materials and an alumina standard into the furnace through an observation port. A port location that was easy to monitor and providing the most severe conditions was selected. The average temperature in that region of the tank was in excess of 1500°C. All of the specimens were left in the tank for 15 days, after which they were retrieved for micro structural analysis.

Direct observation of the specimens revealed that the alumina standard was greatly affected by exposure to the gases. Volume expansion was noticeable and spalling of the surface was easily observed. SEM/EDS analysis revealed that a calcium aluminate layer had formed on the surface of the standard, consistent with previous studies. The yttria candidate materials also showed a small degree of reaction with the CaO in the system.

In this instance, the CaO reacted with free silica in the surface of the yttria compositions to form calcium silicate. Calcium silicate has a relatively low melting temperature and would adversely affect the performance of a sheath comprised of yttria. The yttria used in the creation of the sample had a 99 wt.% purity, with the balance predominately silica. The high density, zirconia sheath material was not affected by the 15 day exposure.

To best accomplish the objectives of the project, it was decided not to fabricate outer protective sheaths using the more exotic materials investigated in this effort. These materials are currently being evaluated to determine their suitability for proposed further improvements to the SVS glass sensors. In particular, AccuTru is continuing the evaluation of the zirconia sheath materials and anticipates future testing in a glass melt tank.

4.0 Host Site Melter Selection and Test Criteria

4.1 Host Site Locations

The initial design of the project called for one test furnace from each segment of the glass industry. The test plant sites needed to be willing to provide furnace access and technical assistance for the installation, in addition to clearance for insertion of "foreign" sensors into the melt environment. During the development and testing period, one of the companies agreeing to participate in the beta testing was sold and the new owners closed the plant, which was scheduled to receive the test sensors. Two of the other beta test sites opted out of the process due to internal corporate constraints on time and budget. It was ultimately determined that the use of two furnaces at Corning would provide sufficient data to validate the performance and reliability of the sensors in a 3 to 4 month test.

4.2 Establishing Test Criteria

Test protocols and procedures were developed and forwarded to the Department of Energy for review. The plan included a text matrix, and was expanded to a minimum of 3 months. AccuTru was responsible for the supervision of the installation, performing the initial calibrations, monitoring of initial operations, and making of any required adjustments to customize the system to the host furnace operations. The test criteria included comparison of the life, stability, accuracy, and validation of temperature data when compared to sensors currently in place in the glass melt furnaces.

Test Criteria

Construct two SVS probes that met or exceeded Corning's requirements for insertion into a melt tank.

Construct two thimbles that met or exceeded Corning's requirements for insertion into a melt tank.

Install one each in crown of the selected melters.

The systems were to be installed in the most hostile section of the melters if possible.

The immersion depth was to be as close to what is typical of the active sensors in the other measurement ports.

The temperature standards are to be the operational sensor temperatures on either side of the test probes. Using estimated temperature differentials and any known error corrections the test port temperatures (TPT) will be estimated. Deviation of more than 4.25°C from the TPT will be considered failure.

Validation feature verification shall be against the TPT.

The life standard for the beta test system alumina configuration was estimated to be 3 - 6 months of service in a hostile environment.

Mid-test modifications to the electronics are permitted, but not to the probe.

Data from each,test unit shall be collected at least every 20 minutes while the probes are in service.

Short term testing at higher data collection rate may be done to check the responsiveness of the test probes to furnace temperature changes.

The data will be forwarded to AccuTru monthly.

AccuTru developed the test criteria, with the input of Corning and DOE. The original criteria and modifications were reviewed with and approved by DOE.

5.0 Design and Construction of the SVS/3500 Sensor

5.1 Outer Protective Thimble

The sensor design includes both an outer protective thimble and an inner protective sheath for the sensor. Both the thimble and sheath were constructed using high purity alumina. The protective thimble was a closed end alumina ceramic sheath, provided by AccuTru, approximately .987 inches in diameter. The thimble was cemented into a stainless steel mounting unit, which was threaded to accommodate the SVS/3500 sensor. The mounting unit was 2.5" in diameter, by 2" in height. The weight of the mounting unit allowed the assembly to be inserted into the temperature measurement port and remain in a vertical position once the sensor was installed, without having to make an FPT connection to the furnace.

The outer protective thimble was designed so that should it fail, the alumina would remain suspended in the port and not fall into the melt. In consultation with Corning and the DOE, we elected not to platinum coat the thimble. AccuTru and Corning wanted to monitor the verification process as the system failed and without platinum protection of the thimble, we anticipated that the bare alumina would cause the sensor to fail at a significantly faster rate by speeding up failure mechanisims.. Based on past experience, it was estimated that the alumina sheath would fail during the 90 day test.

As part of the project, AccuTru conducted research into candidate ceramic materials that might replace the use of platinum in glass melters. The research was conducted in association with Dr. Jeff Smith at the University of Missori - Rolla, and Corning.

The first phase of the research project was to study the failure mechanisims of sensors from a representative glass melter. At the completion of the analysis, three types of ceramic material were selected for inclusion in the test. These candidate materials were then tested in a laboratory melter, The glass composition was a soda-lime-silica glass with high alkali (Modified ASTCM C-621) The candidate materials were exposed to a temperature of 1700°C for periods of from 6 to 24 hours, using a platinum crucible with castable backup in a dense magnesia chamber.

After the completion of this phase of the research, candidate materials were selected for introduction into a glass melt tank for further corrosion studies.

Candidate materials were secured to 2" diameter alumina tube and extended into crown region of glass tank. An alumina sheath material used as control. Placement location in the furnace was determined by Corning representatives. The specimens were removed after 14 days in the tank.

An analysis of the alumina control showed evidence of calcium specie(s) (likely from batch carryover)that reacted with the alumina to form calcium aluminate compounds (predominantly CA6)

Yttria Composition

Calcium specie(s) reacted with free silica in yttria and alumina paste used to hold specimens in place to form calcia-alumina-silicate layer on surface

Dense Zirconia Composition

No corrosion detected, cracks observed after heat treatment caused by thermal stresses.

Conclusions drawn show that limited signs of vapor corrosion detected in post-mortem analysis or in industrial corrosion test, instead batch carryover seems to have caused the observed degradation Vapor species may play a secondary role, serving to flux the compounds that form from reaction of the batch carryover with the sheath materials.

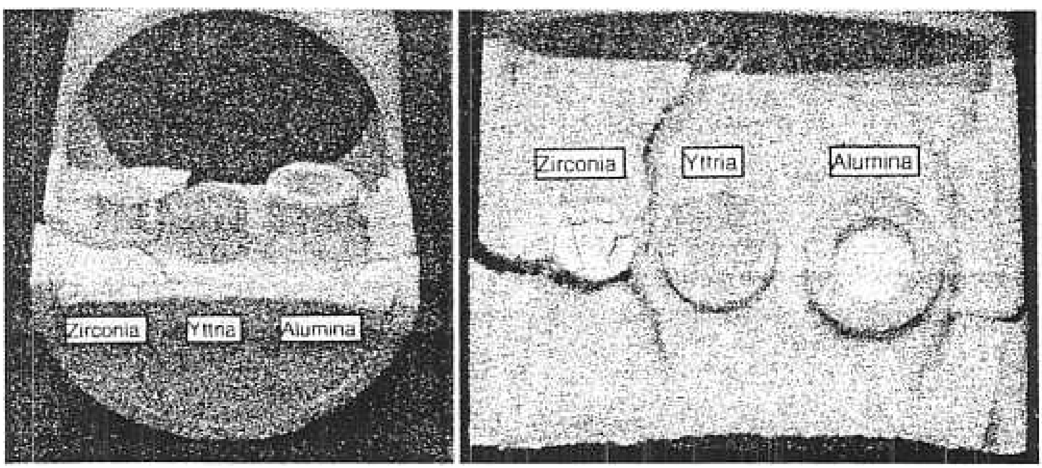


Figure 5.1 Photographs of test samples in sample holder prior to placement in melter and samples shown after completion of the test.

Dense materials and materials with reduced levels of impurities are more resistant to the glass tank environment

Free surface reductions have a large impact on performance, demonstrated by the fact that high density versions of alumina showed marked improvement in corrosion resistance.

Reactions more readily occurred with impurities than with the base materials. Sheath material chemistries can be tailored to provide greater resistance to the glass tank environment.

Yttria and zirconia compositions resulted in improved corrosion resistance as compared to the alumina control, modified versions of these materials seem promising in this application.Solid cylinders of zirconia and yttria used for the industrial glass tank corrosion study fractured during use or upon cooling due to thermal stresses caused by the geometries of the test specimens.

Tube geometries are far superior to solid cylinders because the thermal gradient that develops is much less severe resulting in reduced thermal stress development.

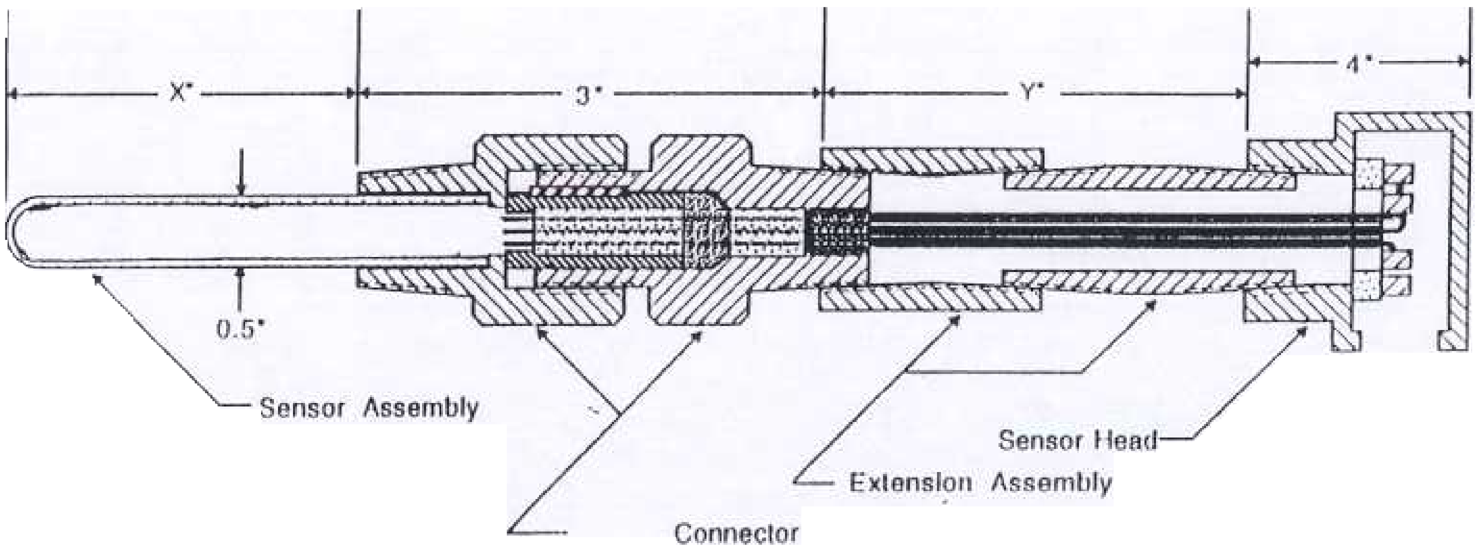
Due to the time constraints of the project, we were not able to fabricate a yttria or zirconia sheath to our specifications for the test. Our research in this area is continuing.

Additional research on sheath material is being conducted in a cooperative project with the Los Alamos National Laboratory.

5.2 Design and Fabrication of the Sensor

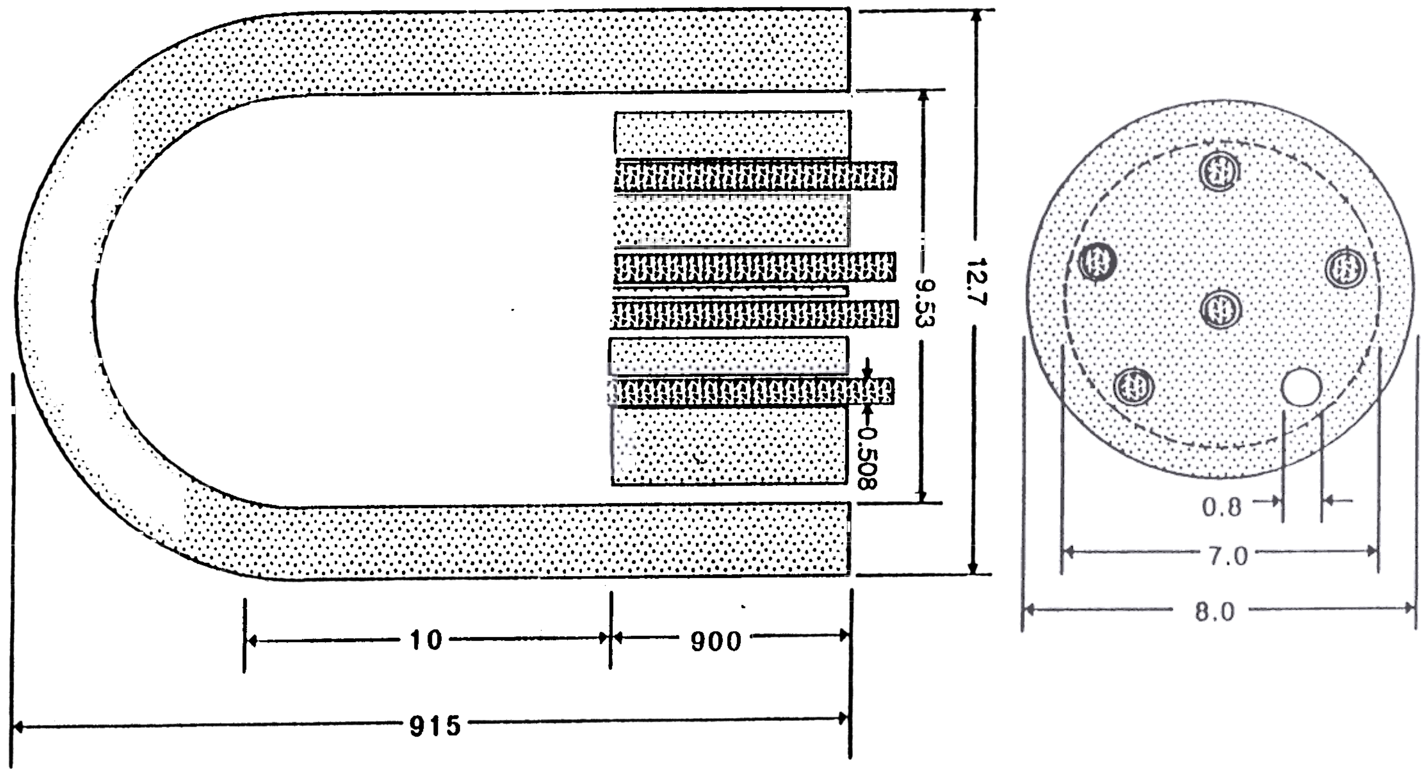
Figure 5. 2 shows the connector detail for the melt sensor. The outer protective sheath is not shown in this drawing. Figure 5.3 provides an enhanced enlargement showing the insulator components at the tip of the sensor. The tip contains the sensor elements that provide the matrix of data signals for the remote electronics used to validate the temperature readout. Figure 5.4 provides additional details of the connection/wire feedthrough for the melt tank sensor. The construction of the connector is critical to the proper operation and life of the sensor.

Figure 5.5 is an outline drawing of the entire sensor, showing its basic features. Figure 5.6 is an outline drawing showing general physical proportions of melt tank sensor. Finally, Figure 5.7 shows the details of wire element terminations for the melt tank sensor.



Note 1: "X" length - 18 to 36 inches.
Dimension is specified by each industry to fit the individual furnace application.
Note 2: "Y" length - 3 to 24 inches, and same comment as Note 1.
Note 3: This drawing is not to scale.

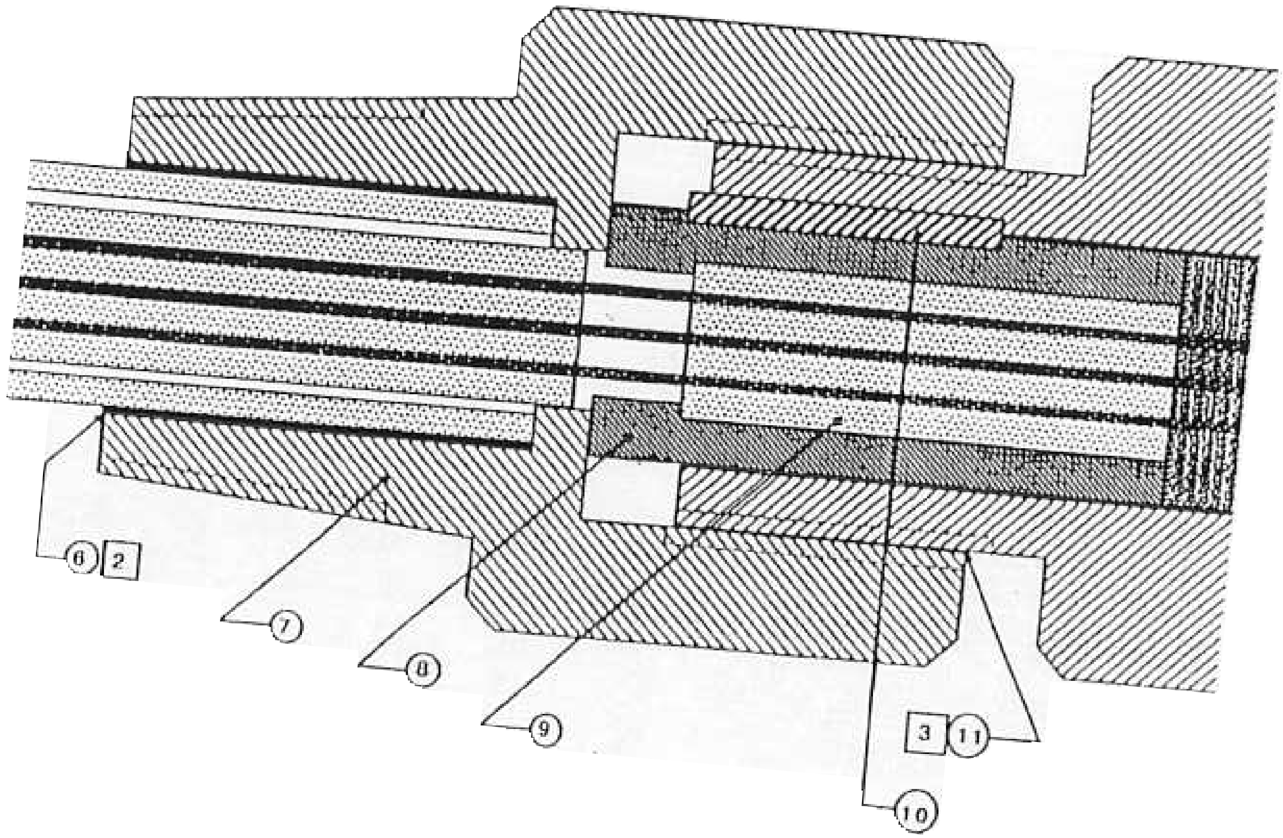
FIGURE 5.2 Drawing showing connector detail for melt tank sensor NOTE: See Section 5.1 for Corning specifications



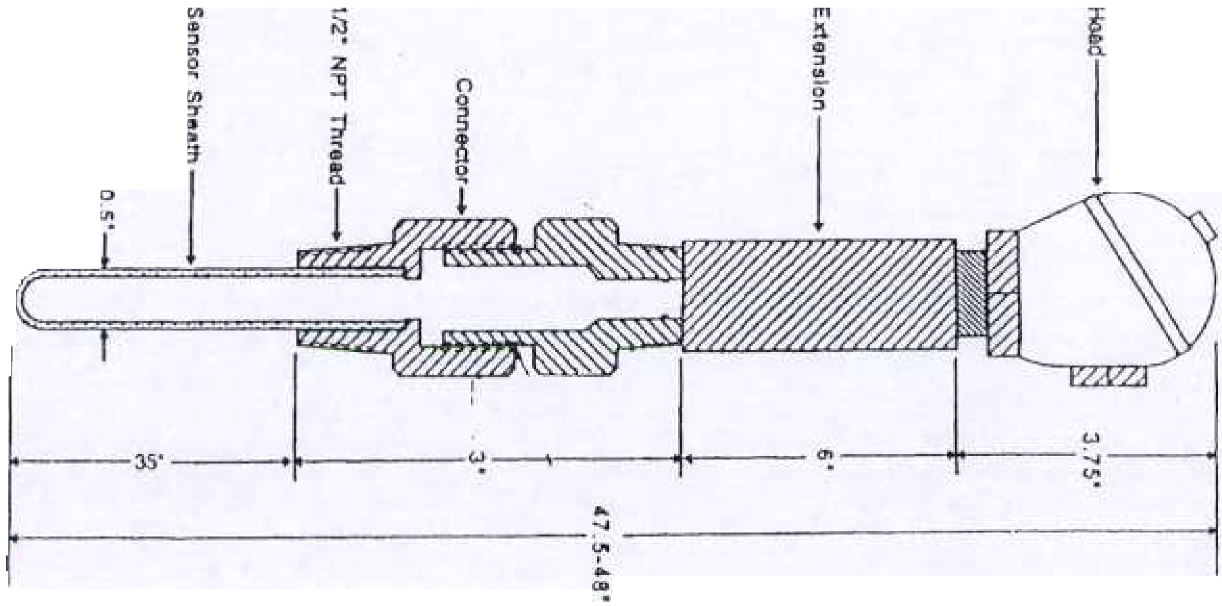
NOTE: All dimensions are in millimeters.

NOT TO SCALE

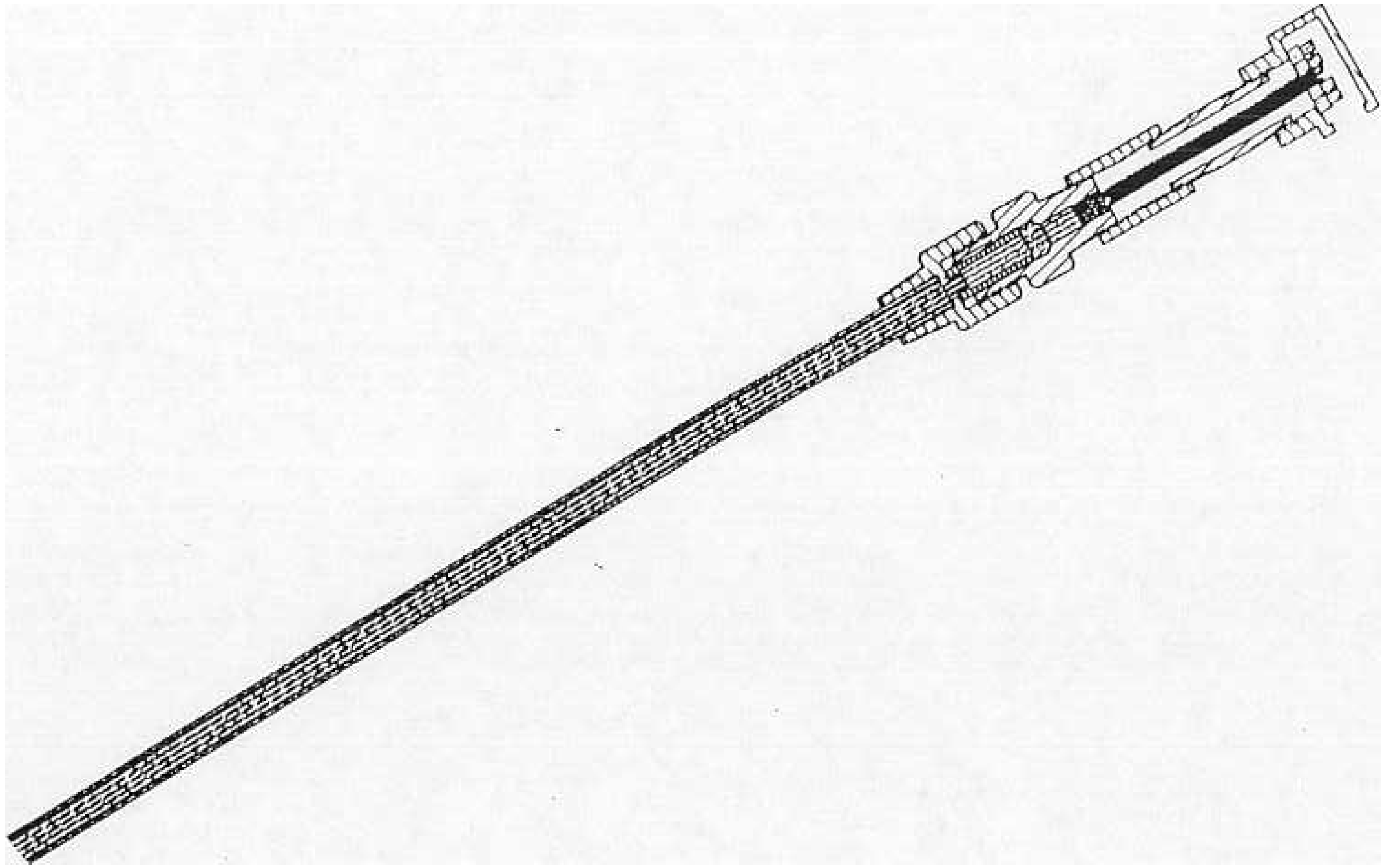
FIGURE 5.3 Enhanced enlargement showing insulator components in sensor tip.



Enlargement sh… …ns …onnection … feed through … me … tank sens…



IGURE 5.5 Outline drawing showing basic features of melt tank temperature sensor.



F] GURE Outl dra ıg showing general phy ical proporti of m tank ısoı

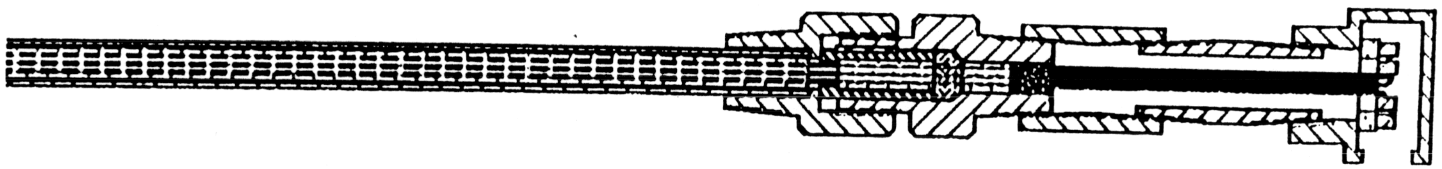


FIG RE Deta of re term att for th mel tan

6.0 Host Site Installation, Start-up, Checkout and Training

6.1 Melter Tanks Selected

Corning, Incorporated, as a partner in this project agreed to allow use of two of their melt furnaces for testing of the SVS sensors.

In order to maximize the results of the testing, it was agreed that two different furnaces would be utilized for the test. One of the furnaces is an oxy-fuel furnace and the second is a regenerative furnace, each operating at different temperatures and each with a different environment. In addition to the different firing methodologies, the glass composition for each furnace was different. This provided the opportunity to look at temperature, cycling, and slightly different melt composition factors in evaluating sensor performance.

6.2 Locations Selected

Because these installations were passive systems (not connected to the furnace control system), the ports selected for installation were located away from both the charge end and the refiner end. One of the criteria for selection was to find a location where there were adjacent sensors currently installed and operating so that data from those sensors could be collected and compared to the SVS sensor. This would allow for estimation of Test Port Temperatures based on Corning experience. Because of the large mass of the melt, and the tight tolerances in temperature control, the furnace temperatures are fairly constant. In the regenerative furnace, although there are swings in temperature, they maintain a high level of consistency. Thus, the performance of the SVS sensor could be determined by comparing the readings of the adjacent sensors, with the SVS sensor.

6.3 Installation, Start-up, Checkout and Training

In April of 1999, two SVS sensors were installed in the previously selected melt tanks at the Corning facility. A team of AccuTru and Corning employees accomplished the installation. These systems were defined as "passive" in that they were not integrated into the existing melt furnace control systems, but rather were stand-alone units with temperature displayed on a separate data terminal.

OXY-FUEL INSTALLATION

One system was installed in an oxy-fuel melt tank. The data terminal was installed and the remote electronics unit was then installed in an area adjacent to the furnace. One concern was the high ambient temperatures in the area and their possible affect on the performance of the electronics module. Temperature measurements were taken and it was determined that the electronics would see a temperature of up to 70°C. To minimize possible radiation heating of the containment box for the electronics, an insulation blanket was installed on the cover of the box.

The wiring of the remote electronics to the data terminal in the control room was made using standard shielded pair communications wires to provide a data link between the electronics module and the data terminal. The length of the cable run was approximately 75 feet.

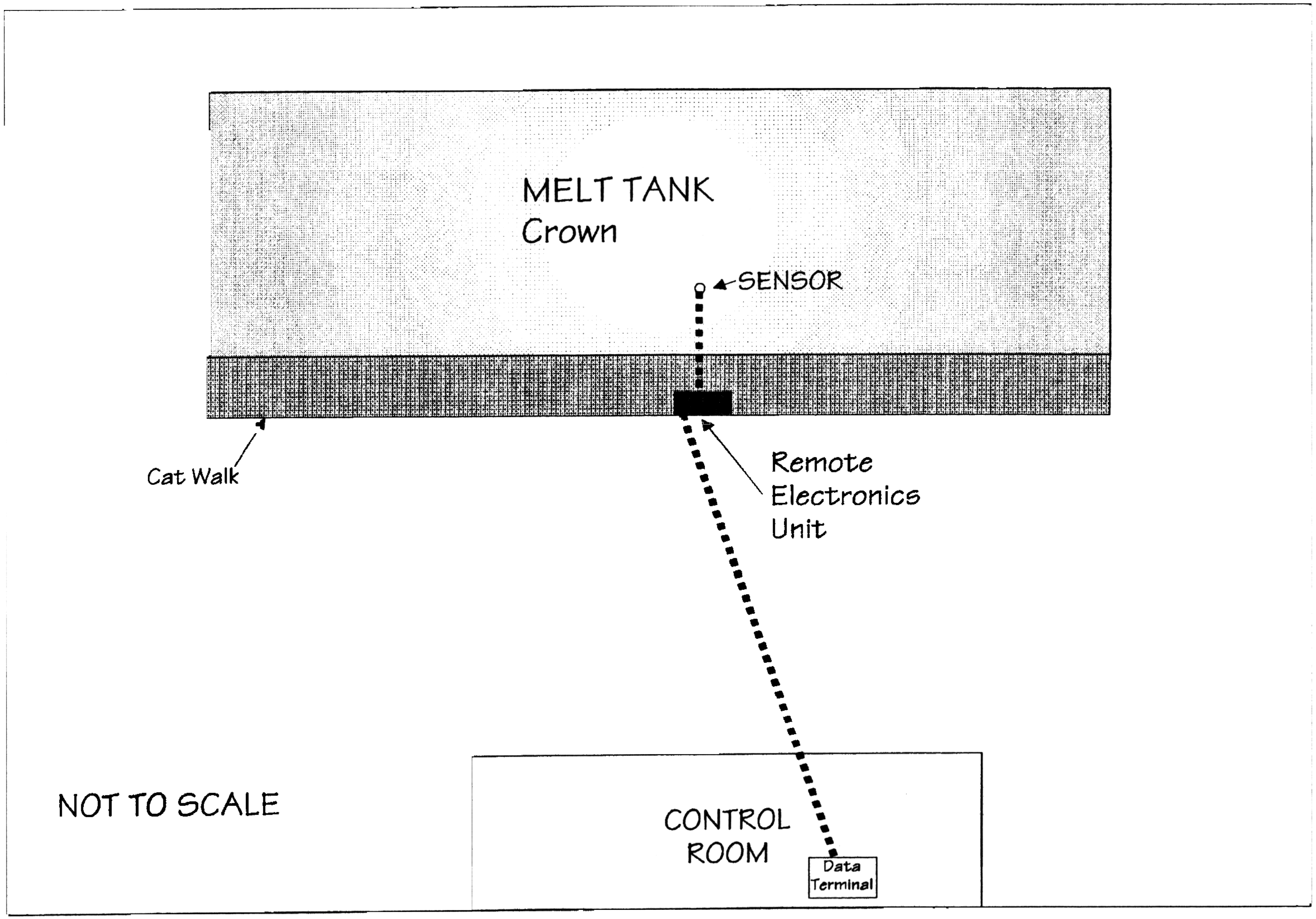
The final steps in the installation of the first sensor were the connection of the sensor's extension wire to the remote electronics module. Upon completion of this task, the sensor was preheated by placement on top of the crown for approximately one hour. Then the port in the melt furnace was opened and the sensor placed at the top of the opening to further preheat the ceramics before full insertion. After 1 minute, the sensor was placed in the port and the system was activated to begin data collection. A wiring diagram of the installation may be found on page 6.3.

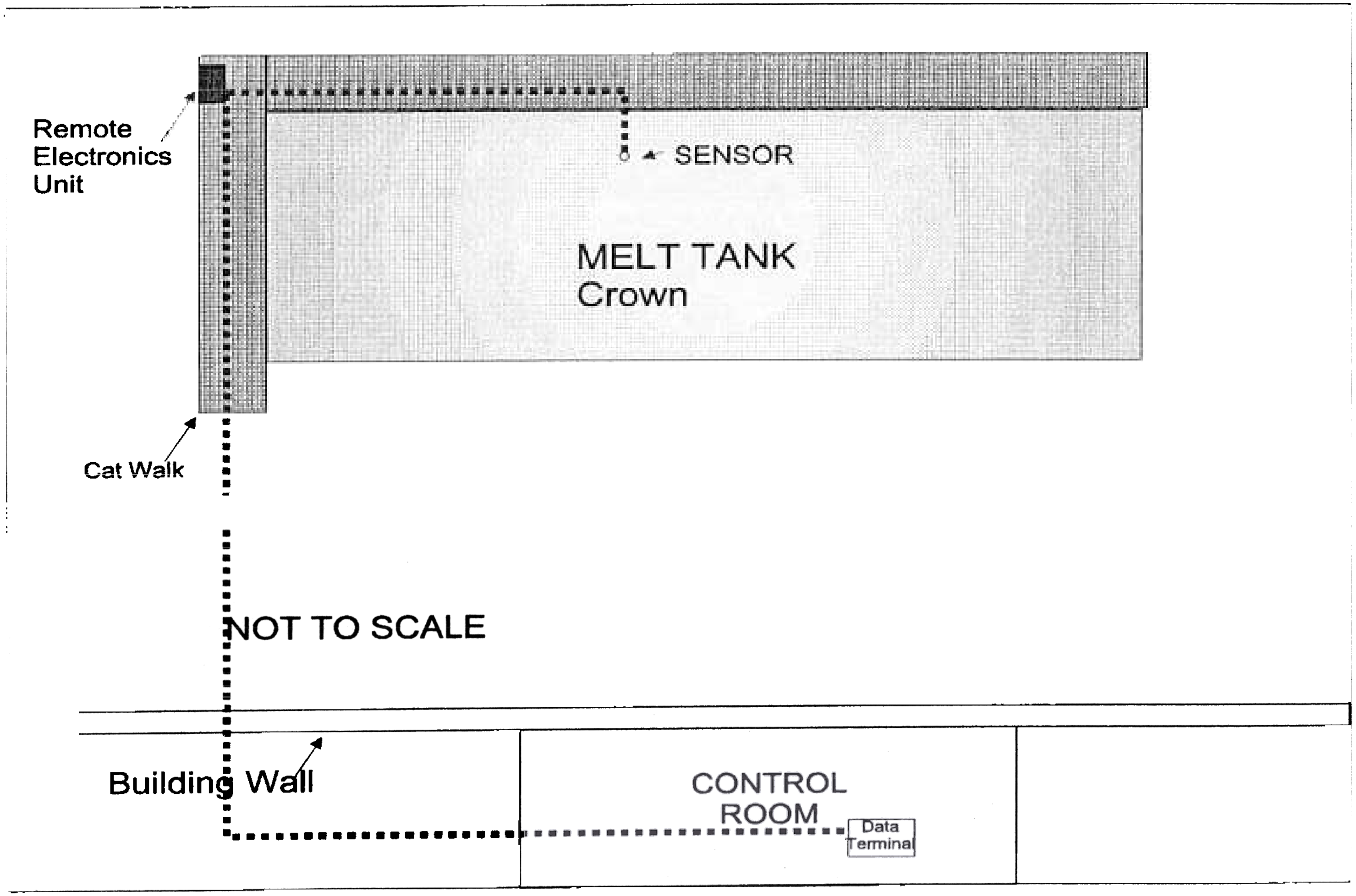
REGENERATIVE INSTALLATION

The second sensor was installed in a regenerative melter. Because of the location of the furnace and port, the installation was somewhat more complex, requiring longer runs of both extension wire and communications cable with the extension cable being approximately 75 feet in length and the communications cable approximately 200 feet long. In addition to testing of the sensor performance, this installation provided the opportunity to determine any artifacts that might be introduced by differing extension and communication cable lengths.

The remote electronics module was attached at the end of the furnace, as contrasted with the Oxy-fuel installation, which was installed at the side location. This location was further away from the furnace and thus ambient temperature was not considered a problem. The communications cable was then connected from the remote electronics unit to the data terminal. This cable run was approximately 200 feet, and was routed into another building, where the control room was located.

The extension cable was then connected to the sensor and the measurement port opened. The sensor was preheated for approximately 1/2 hour in tank ambient air and approximately 1 minute at the top of the port opening. Then the probe was slowly inserted into the test port, which took approximately one minute.. The extension wire was then connected to the remote electronics unit and the data collection function was activated. A wiring diagram of this installation may be found on page 6.4.


MELT TANK
Crown
SENSOR
Cat Walk
Remote
Electronics
Unit
NOT TO SCALE
CONTROL
ROOM
Data
Terminal


Remote
Electronics
Unit
SENSOR
MELT TANK
Crown
Cat Walk
NOT TO SCALE
Building Wall
CONTROL
ROOM
Data
Terminal

6.3 TRAINING

Corning Incorporated staff members were oriented on the operation of the SVS system. In addition to monitoring the temperatures, the staff members were shown how to download data collected from the sensors and forward the disks to AccuTru for analysis and interpretation.

7.0 Mid-test Modifications

One of the unknowns was the performance of the sensor and electronics in an environment with considerable electrical "noise." The design of both the board and extension cable had considered the need for protection against plant noise, but it was anticipated that some modifications to the electronics might be required to make certain that errors introduced by plant noise were eliminated.

After an initial period of testing, it was determined that the electrical fields in the environment of the furnaces were indeed introducing noise in the signals being processed by the electronic units. This was significant enough to cause some of the internal sensor readings to be outside of tolerances. It did not meet the design criteria AccuTru had established for the electronics. Two mid course modifications were made to improve the performance of the electronics.

First, AccuTru's electronics alliance partner developed a revised strategy and design for electronics noise rejection and produced two modified microprocessor boards. These boards were tested in the lab and a new set of calibration data was generated and installed on the boards. The boards were then shipped to Corning and installed in place of the two original boards by Corning personnel. The improved boards made a marked improvement in the tightness of the calibration matrix and increased the overall confidence in the measurements.

Somewhat later a second modification was also suggested to improve grounding of the shield of the extension wire cable from the probes to the electronics package. This required attaching the cable shield to a different point on the board. A set of jumpers with instructions for installing them was shipped to Corning and installed by Corning personnel. This modification made another incremental improvement in the tightness of the calibration matrix further increasing confidence in the measurement outputs.

Some further testing of different grounding points for unused wires in the extension cable was conducted at AccuTru's request. However, no additional substantial modifications were made.

8.0 Beta Test Data Collection, Presentation and Analysis

8.1 General

Two AccuTru SVS Sensors were installed in melt tanks at the Corning facility on April 29, 1999. Since that time, data has been transmitted faithfully by Corning personnel to AccuTru for extraction and analysis. Output data from the sensors in the form of Daily Average temperatures has been plotted in Figure 8.1. The Sensor installed in the Oxy/Fuel Melt Tank, is referred to as the "Red" Sensor. This sensor has recorded a fairly steady temperature in the range of about 1520 degrees C throughout the test period. The second Sensor, referred to as the "White" Sensor, was installed in an Air/Fuel Melt Tank. The White Sensor has recorded a temperature in the range of 1630 degrees C during most of the test period. As can be seen in Figure 8.1, a period of reduced temperature operation of the one tank occurred near the end of July during which the temperature of that tank was reduced to around 1200 C. The small gaps in the graphs are because of missing data for those time periods. Both the Red and White Sensors have performed reliably since they were installed and were continuing to generate reliable measurements as of 11/21/1999 when this report was generated.

Sensor data is gathered and processed by the AccuTru microprocessor board more frequently than once per second. It was determined that a one-minute sampling frequency was appropriate for this test. Therefore, temperature outputs from the sensors are recorded by the AccuTru system at one-minute intervals. Data files for both sensors were transmitted on a weekly basis from Corning to AccuTru.

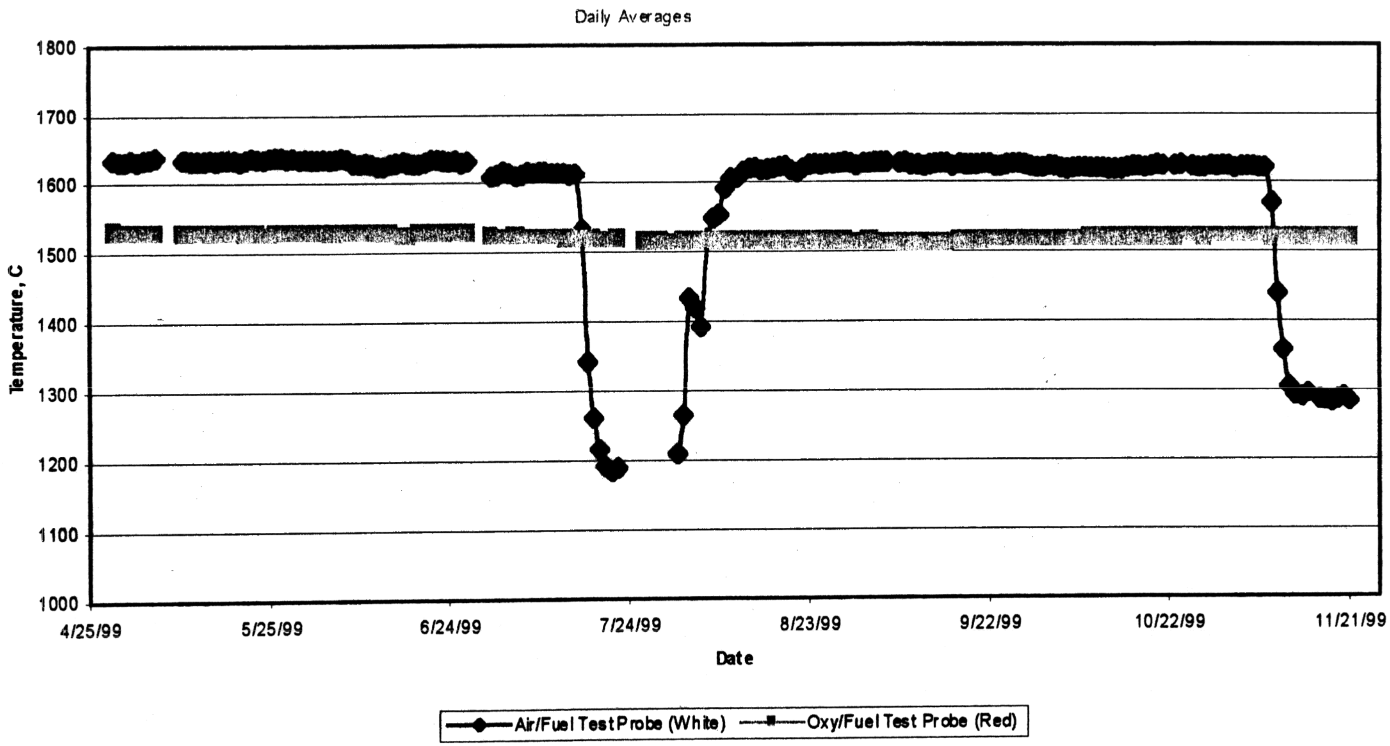
There is considerable electrical noise in the plant. Some shielding and filtering modifications had to be made to isolate the electronics from induced currents. See section 7.0 for details.

For comparison purposes there are standard Corning sensors reasonably close to the SVS test probes in both tanks.

8.2 Oxy/Fuel Melt Tank

The Oxy/Fuel melt tank is a large scale industrial melter. The Red Sensor is installed in the crown of the tank measuring the temperature of the vapor space approximately 10 feet above the molten glass. Figure 8.2 shows temperature history for a typical 24-hour period.

Figure 8.1 SVS Test Probes in two Corning Glass Tanks



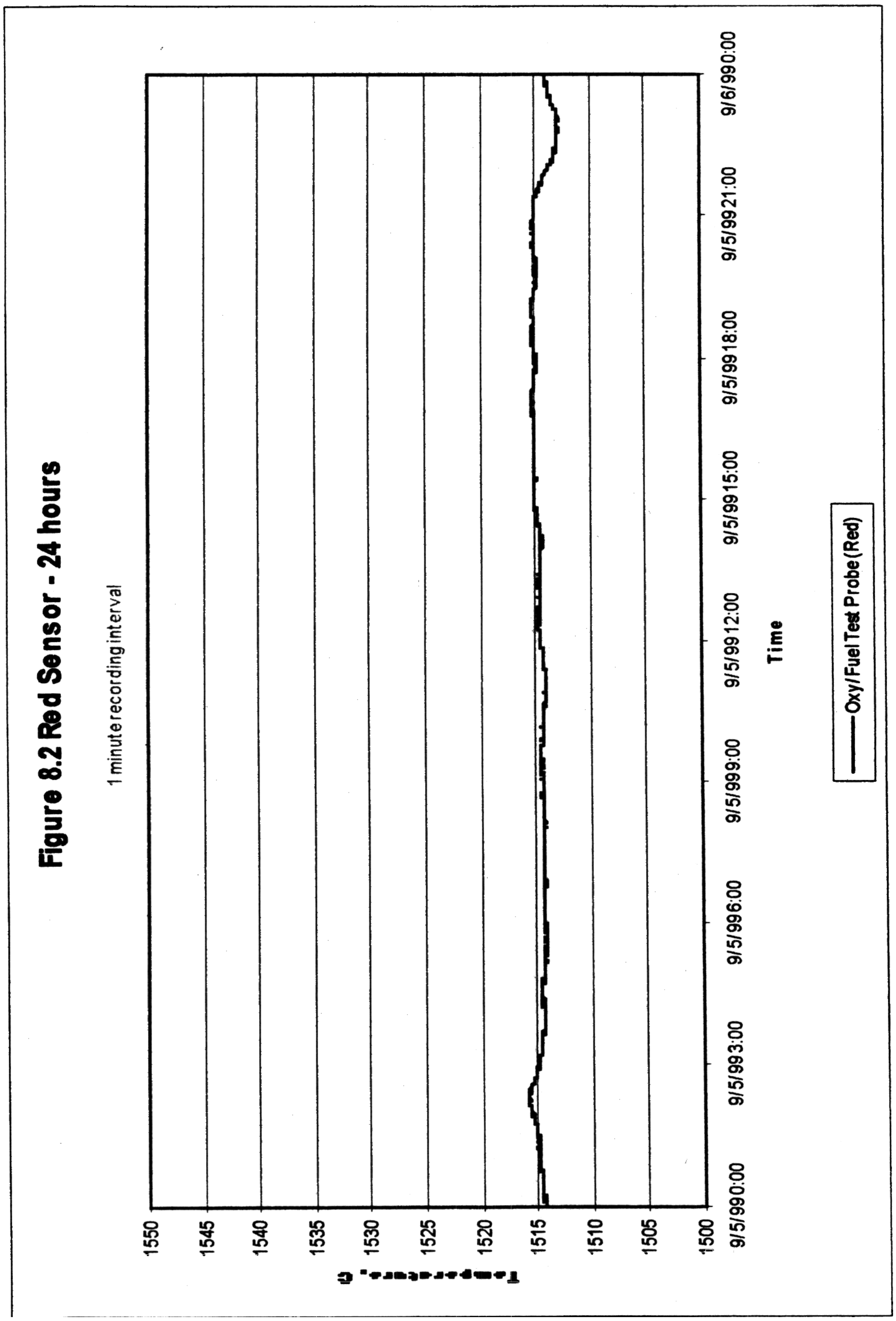


Figure 8.2 Red Sensor - 24 hours

The sensor easily picks up the relatively small variations in temperature in this tank. Figure 8.3 plotted on an expanded scale illustrates the sensitivity and responsiveness of the Red Sensor over the same period.

The Red Sensor has been in a "Green" condition signifying that it is healthy over the entire time since it was installed in the tank. This means that the temperature output of the sensor is traceable back to a NIST" standard and is within at least standard limits of error for a platinum type sensor at this temperature. (See Section 8.5 on Status Indicators)

8.3 Air/Fuel Melter Tank

The Air/Fuel melt tank is also a large scale manufacturing melter. The White Sensor is installed in the crown of the tank measuring the temperature of the vapor space approximately 10 feet above the melt. Crown temperatures are used for temperature control of the melt and good models of temperature profiles in the tanks exist. Figure 8.4 shows temperature history for a typical 24 hour period.

The temperature in the tank cycles about 20 degrees every 20 minutes. Figure 8.5 showing this cycling over a 2-hour period illustrates the sensitivity and the responsiveness of the probe.

The melt tank in which the White Sensor is installed went through a period of reduced temperature operation for several days in July during which it was cooled down to about 1200 C (refer to Figure 8.1). The White Sensor was in a Yellow or "Caution" condition when first installed. When the improved electronics were installed it went to a Green or "OK" status but several days later went back to a Yellow or "Caution" condition. The Yellow or caution condition indicates that there is still sufficient data to ensure that the sensor output is traceable to a NIST Standard, but that some of the elements of the sensor may have become impaired.

This demonstrates the key validation status feature of the SVS System, which is its ability to warn the operator in advance of possible deterioration of the sensor probe or compromising of the measurement signals. A more detailed explanation of this feature is presented in Section 8.5 Status Indicators. Even though it is in the Yellow condition, the White sensor continues to perform satisfactorily and provide validated NIST traceable readouts as this report is written despite being somewhat impaired.

While the White Sensor was green immediately following the installation of the improved electronics, the overall confidence level has never been as high as that of the Red Sensor. It appears that there is more electrical noise affecting the White Sensor than the Red. There could be more electrical induced noise in the vicinity of the White Sensor. Also, the extension cable required for the White Sensor is somewhat longer than for the Red and the communications cable to the control room is considerably longer. It also turns out that there is a large variable frequency drive much nearer to the White Sensor than to the Red. It is not

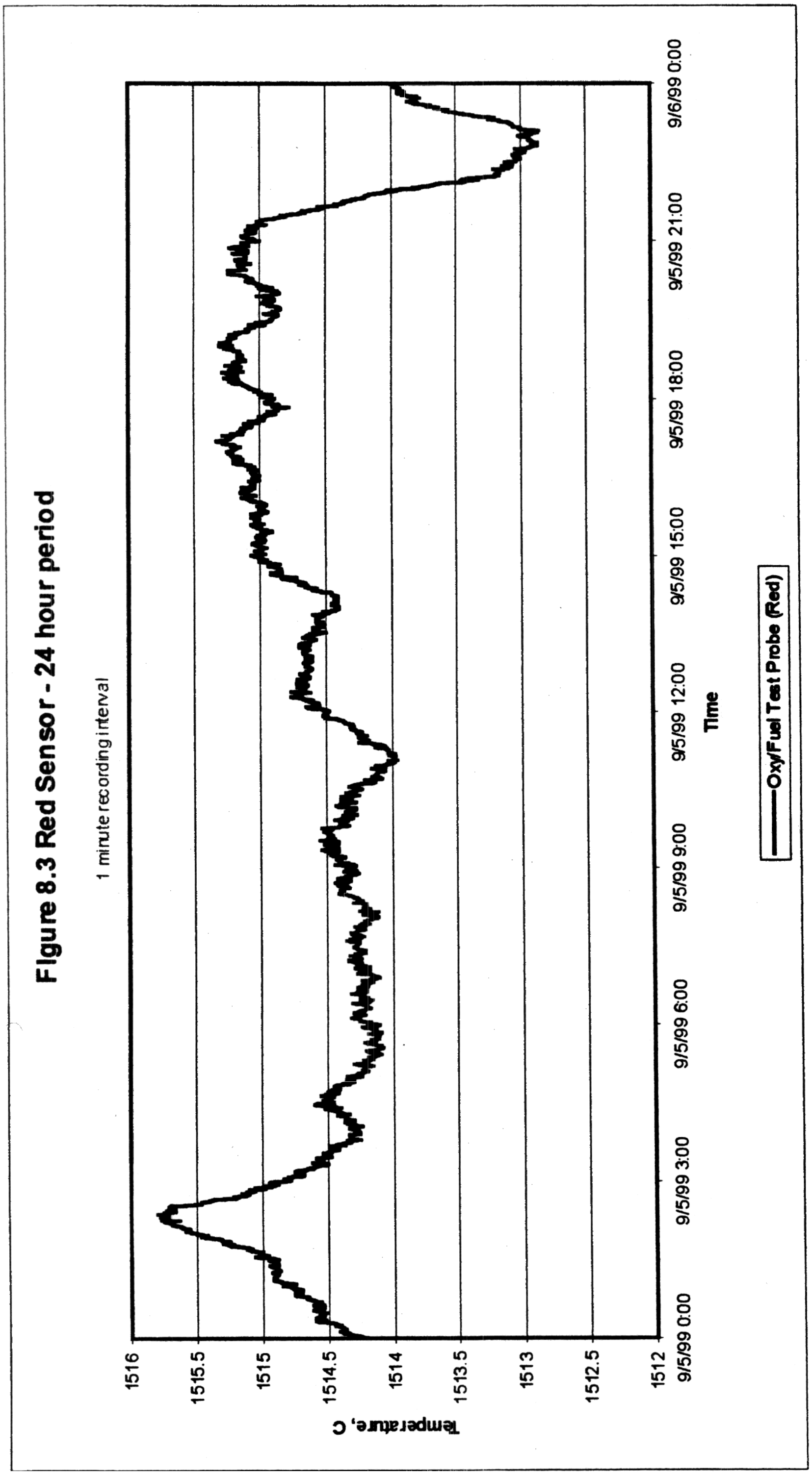


Figure 8.3 Red Sensor - 24 hour period

Figure 8.4 White Sensor - 24 hour period

1 minute recording interval

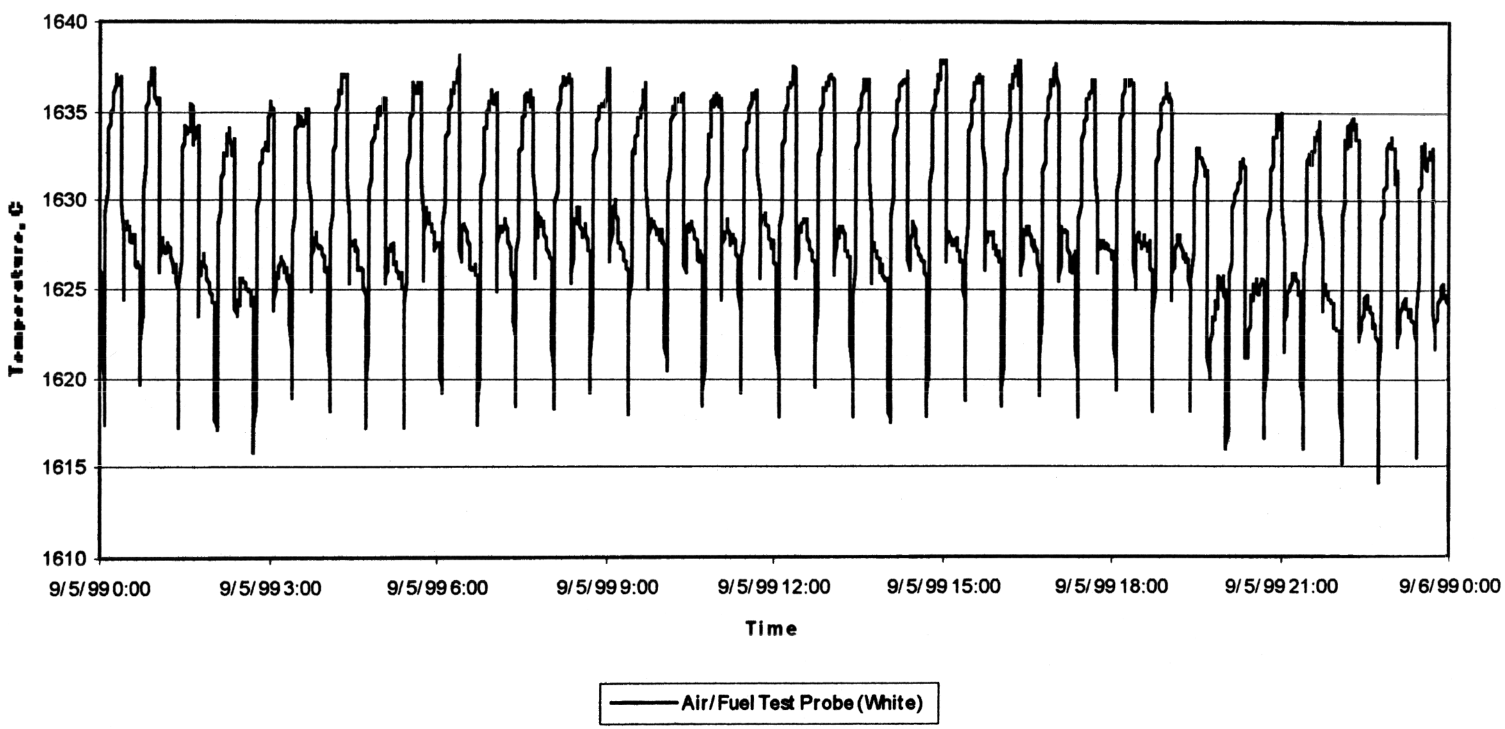
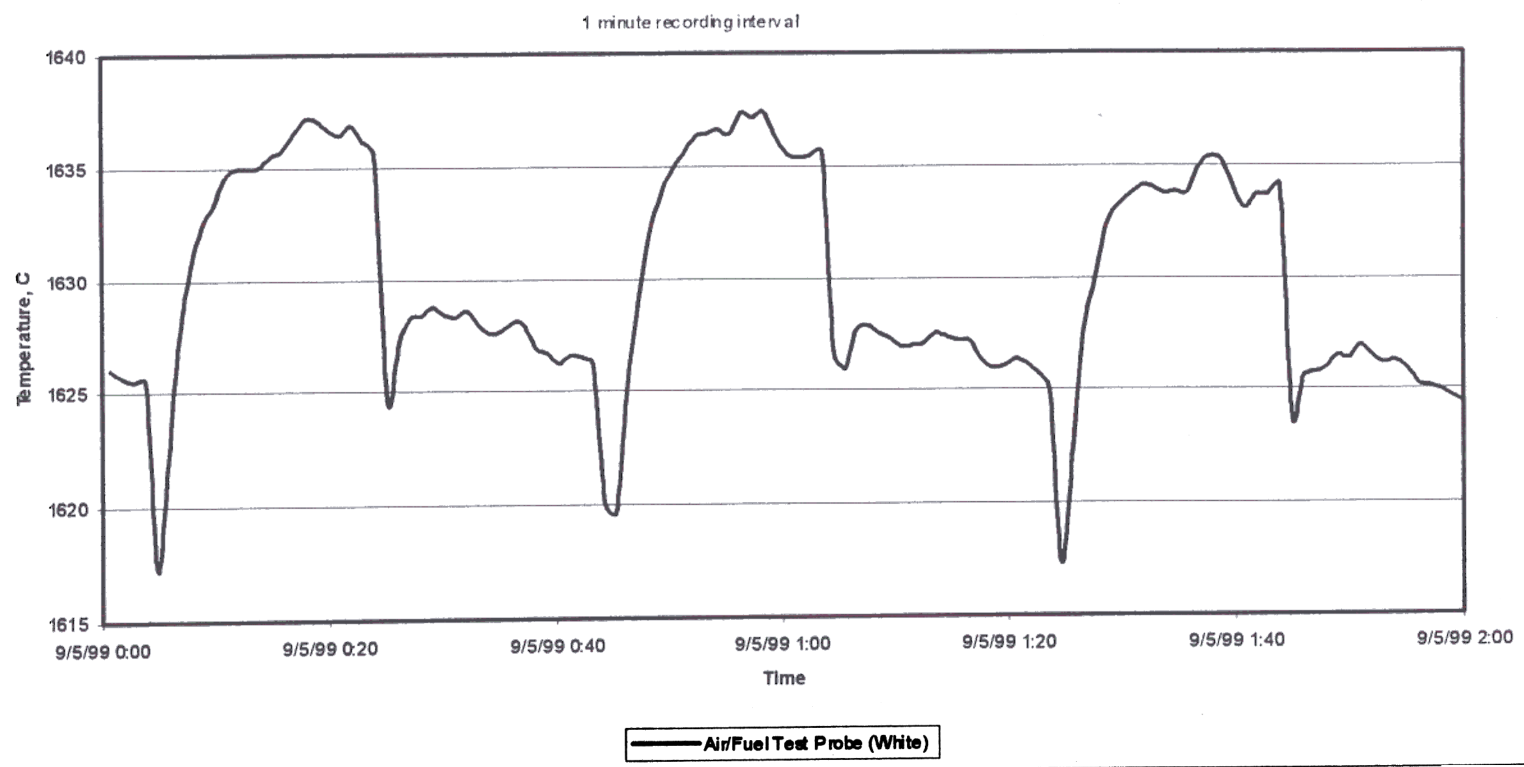


Figure 8.5 White Sensor - 2 hour period



known precisely what is the source of greater noise pickup. Field testing to determine the frequency of the noise can be done to pinpoint the source and eliminate it's effects.

8.4 Probe Accuracy

One of the objectives of the test was to demonstrate the accuracy of the SVS Probe readings. The Red SVS Test probe in Oxy/Fuel tank is installed between two existing Corning standard probes (Corning Sensor OF-1) and (Corning Sensor OF-2). The White SVS Test probe is installed in Air/Fuel tank downstream of Corning standard probe (Corning Sensor AF-1). Both SVS Test probes have performed reliably and tracked their respective comparison sensors for over 6 months. They are continuing to provide validated temperatures as this report is being written.

8.4.1 "Red" Sensor

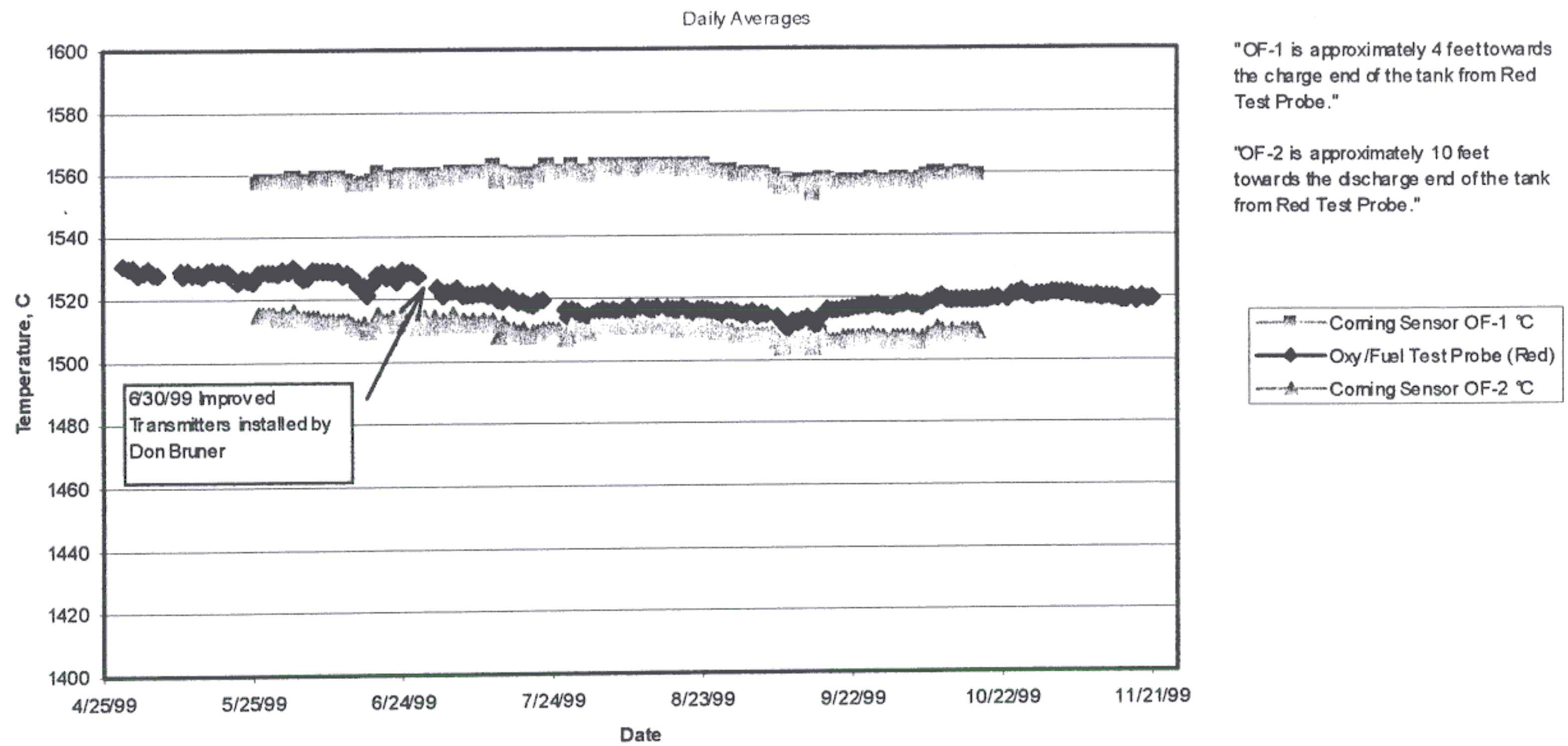
In this Oxy/Fuel Tank, one of the comparative sensors (Corning Sensor OF-1) is approximately 4 feet towards the charge end of the tank from the Red SVS test probe. The second comparison sensor (Corning Sensor OF-2) is approximately 10 feet towards the discharge end of the tank from the Red SVS test probe. Corning collected daily average readings from the both of the comparative sensors for comparison with the readings from the Red SVS Test Probe. Red SVS Sensor Daily average values were calculated from the data collected at one-minute intervals. This data is plotted in Figure 8.6.

Note that there are some interruptions in the data collection on Figure 8.6. These interruptions were caused by either lack of data from the Corning system, or when the data collection and archival system for the SVS system was inadvertently shut down. Note that these figures do not show significant drift over the period of time shown on the charts. This is not untypical for platinum - platinum/rhodium thermocouples. The shift in temperature may be sudden and dramatic. For example, we have industry data showing that a sensor may drift as much as twenty degrees in a period of several minutes, while previously, it was exhibiting a constant temperature readout.

Corning Sensor OF-1, 4 feet upstream, reports consistently about 30-40 deg C higher than The Red SVS probe and Corning Sensor OF-2, 10 feet downstream, reports about 5-15 deg C lower. There is no true reference standard in the tank so we do not know the true temperatures at any of the measuring points. The Red SVS Sensor is reporting between the two standard probes where it would be expected to be and the profile is also about what would be expected.

Soon after installation of the AccuTru SVS test probes and transmitters, it was noticed that considerable noise was being picked up by the electronics. This is discussed in Section 7.0 Mid-Test Modifications. Improved electronic transmitters were developed by AccuTru and installed by Corning on 6/30/1999. A major improvement in noise rejection was seen on both test probes.

Figure 8.6 Oxy Fuel Tank Probes



A modest shift downward in the output of the Red test probe temperature is suggested by the data after the improvements to the electronics package. Unfortunately, data for the 2 days immediately preceding the change was not captured. Subsequent trending and comparison with the Corning Sensor OF-2 sensor suggests that the shift was fairly small. Certainly, after the improvement in the electronics the tracking and comparison of Corning Sensor OF-2 and the Red test probe are very good. However, since the gap between them has been widening somewhat lately, it may be that Corning Sensor OF-2 is beginning to drift from true.

8.4.2 "White" Sensor

In the Air/Fuel regenerative tank, Corning Sensor AF-1 is approximately 2 feet towards the charge end of the tank from the White SVS Test Probe. Corning collected hourly readings from the Corning Sensor AF-1 for comparison with the readings from the White SVS Test probe. Due to the fairly significant 20minute/20degree temperature cycle in this tank it was not appropriate to try to compare directly to the hourly numbers which are being gathered by two independent systems under the test conditions. Daily averages for both probes were calculated and are plotted in Figure 8.7. This figure shows the same interruptions in data collection as seen in Figure 8.6.

Again, there is no true reference standard in the regenerative tank so we do not know the true temperature at either of the measuring points. Corning Sensor AF-1 (2 feet upstream) reports consistently about 20-25 degrees higher than the White SVS Test probe. This difference is a similar relation to the 30-40 degrees difference between Corning Sensor OF-1 (4 feet upstream) and the Red SVS test probe. The sensors track each other very well through the "shutdown" period as well as during stable operation.

After improvements to the electronics, there appears to be a more significant shift downward in the output of the White SVS test probe vs. the Corning Corning Sensor AF-1. This sensor was experiencing much higher electronic noise interference than the Red SVS test probe. Some of the shift can be attributed to the new electronics and their new calibration parameters. Notably, there was also a slight downward shift in the data from Corning Sensor AF-1 at the same time. Since the two systems are completely independent of one another except at the tank, it is possible that some shift in the overall operation occurred. This could be due to a real process change or possible physical movement of the sensors themselves which are in close proximity to one another. Tracking and comparison of the two sensors during the entire test period is quite good.

8.5 Probe Life

Both SVS Test probes have performed reliably and tracked their respective comparison sensors for over 6 months. Normal average sensor life for all of the sensors in this service is 6 to 48 months, depending upon location, for both the Oxy-Fuel melter at about 1520 C and the Air/Fuel tank at about 1630 C. However, normal sensors are platinum coated for

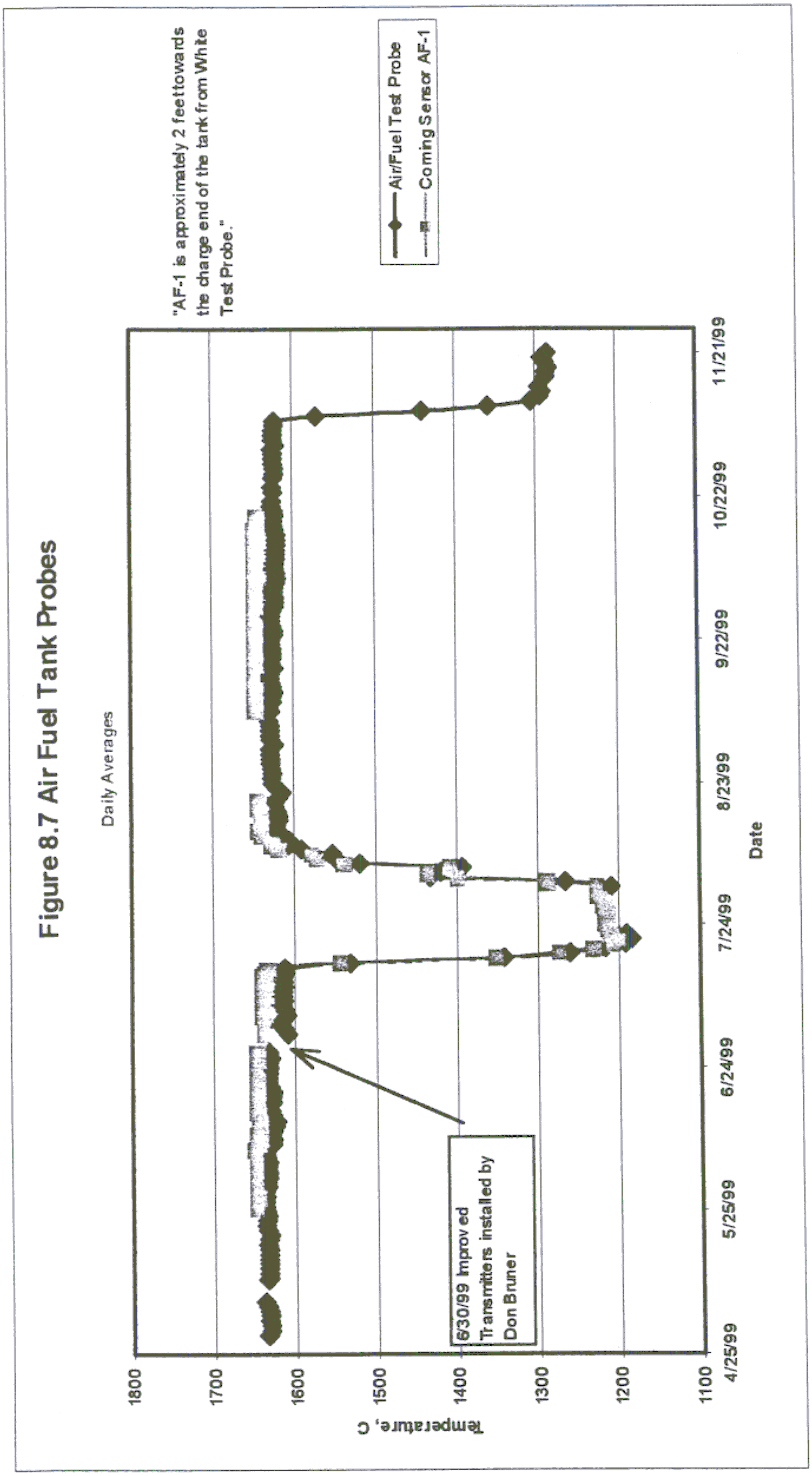


Figure 8.7 Air Fuel Tank Probes

protection and not bare ceramic. Furthermore, normal sensors do not tell you when they begin to drift nor do they quantify the drift. See Section 8.6 on Status indicators. SVS Test probes have exceeded life expectancy for uncoated ceramic tubes in this service and continue to report validated temperatures as this report is being written.

8.6 Status Indicators

SVS Sensors are equipped with a unique validation and reporting system that checks and reports sensor "Status" at regular intervals. Sensor status is validated by comparison of the primary sensor readout vs. a calibration matrix inside the sensor. Multiple readings of several different properties of the thermally sensitive materials inside the sensor are combined in such a way as to eliminate the possibility of individual element drift without detection. Since drift can be detected and quantified, user defined tolerances on accuracy can be specified.

The SVS Sensors in this test are set to maintain readings within Standard Limits of Error for a Platinum Type sensor at this temperature range. For an "S" and "R" sensor, this is .25% and for a "B" Type sensor, it is .5%.

Status is typically reported by displaying the sensor output on a Green, Yellow or Red background and reported in words as either "OK", "Warning" or "Failed" respectively. It can also be reported as a scalar parameter representing the level of confidence in the sensor output. This is illustrated in Figure 8.8 where the status indicator for the Red Sensor is plotted as Percentage Health. After improved electronic transmitters were installed the Red Sensor status indicator has been steady at nearly 99%. In September and October some cable shielding "improvements" were attempted but were unsuccessful. They were undone again on the 5th of November and the health indicator returned almost to where it was before the changes and is in a slight downward trend.

As reported earlier, the Red Sensor has been in a "Green" condition since it was first installed in the tank. A Green condition corresponds to a status indicator of 97% or above. A Green condition indicates that the temperature output of the sensor is validated to be traceable back to a NIST standard and, in this case, is within at least standard limits of error for a platinum type sensor at this temperature. It is clear from the Status indicator for this sensor that the noise rejection was improved when the new transmitters were installed.

When drift or other impairment of the sensor readouts is detected that could eventually lead to inability of the sensor output to be validated, the sensor status is changed from Green to Yellow or "Warning". The White Sensor is in this condition. This is shown in Figure 8.9 where the status indicator for the White Sensor has fallen below 97%.

Prior to the improvement in the electronics, the White Sensor status was somewhat erratic and mostly in a Yellow or "Caution" condition. Immediately following the installation of the improved electronics, status went to Green for several days and then later dropped into

Figure 8.8 Oxy Fuel Tank Probe Health

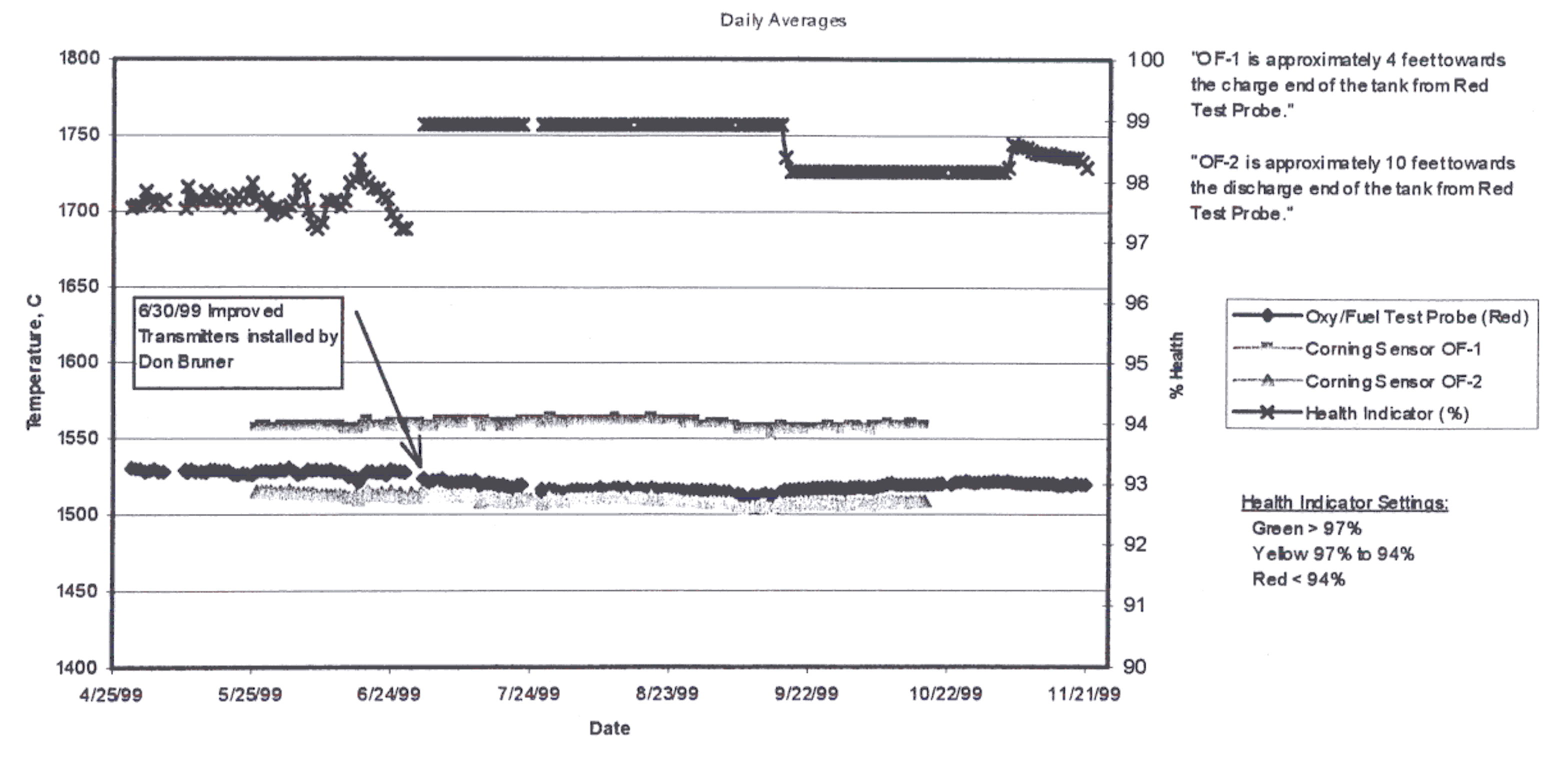
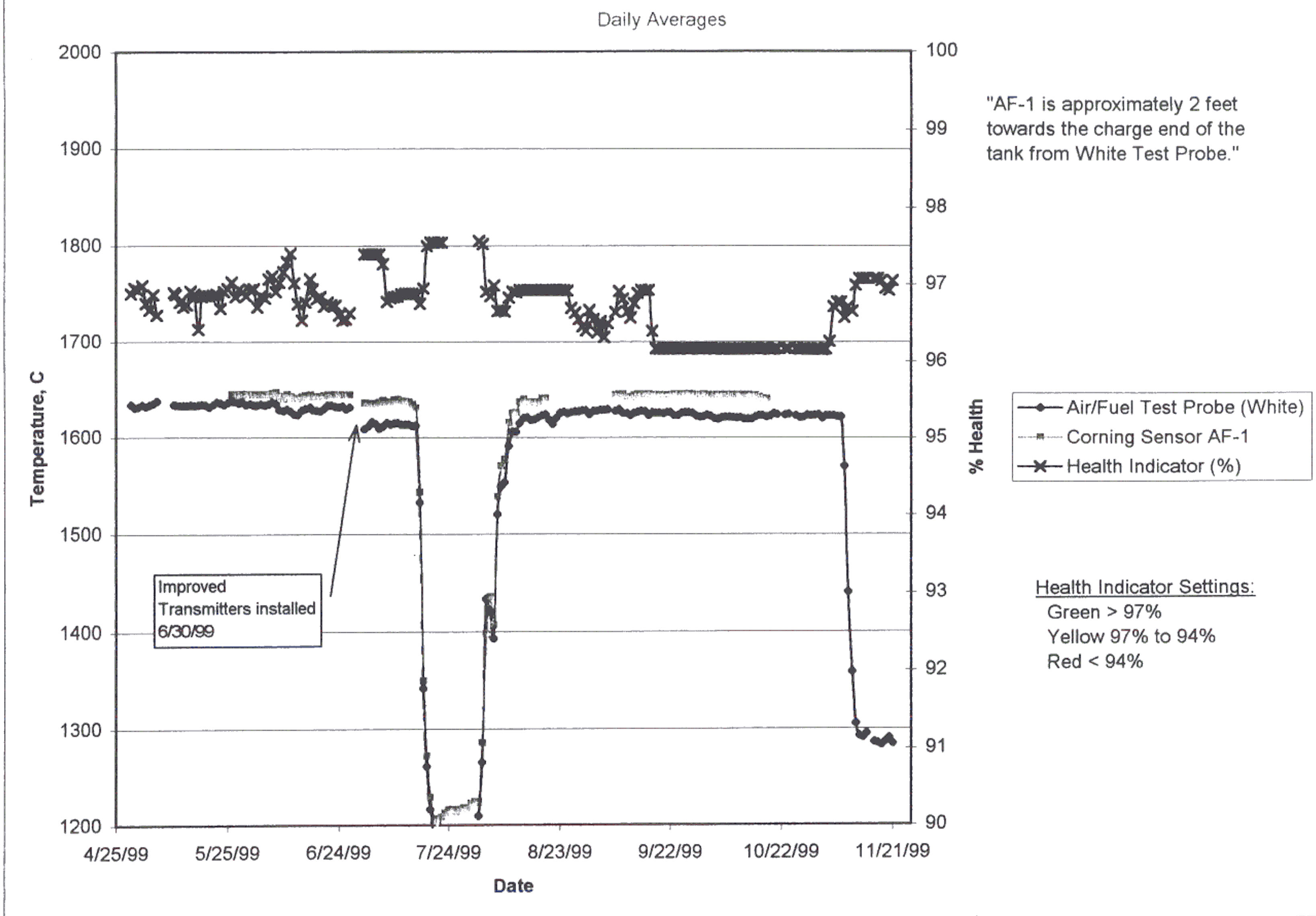


Figure 8.9 Probe Health - Air Fuel Tank



the Yellow range. After the "shutdown" it has consistently indicated the Yellow or "Caution" condition.

The Air/Fuel regenerative tank is operating at a higher temperature and has experienced significant cycling of temperature including the "shutdown" for several days to about 1200 C. Its status was most probably Green when first installed if measured by the improved electronics, but went to a Yellow or "Warning" condition just prior to the "shutdown". The yellow condition indicates that while there is still sufficient data to ensure that the sensor output is validated and traceable to a NIST Standard, some of the elements of the sensor may have become impaired. The sensor output, however, is still within standard limits as defined above.

This illustrates the status feature of the SVS System, which is its ability to warn the operator in advance of possible deterioration of the sensor probe or compromising of the measurement signals. The operator can then plan to replace the probe at the next convenient opportunity.

If enough of the readouts from the internal elements of an SVS Sensor become impaired so that the System can no longer validate the output, it will change to a "Red" status. This would correspond to a status less than 94% and would indicate that the temperature output can no longer be reliably validated as traceable within the prescribed limits and the sensor probe should be replaced. Even in a Red condition the sensor output is as good as the readout of any standard sensor but the Red condition indicates it can no longer be depended upon. At this time, however, the both SVS Sensors are still performing satisfactorily and is providing validated NIST traceable readouts.

9.0 Phase II Objectives versus Accomplishments

9.1 As of this writing, both of the systems are still in service and operating. The Oxy/Fuel Tank system is operating in a green condition and the Air/Fuel Tank system is operating in a yellow condition. The accomplishments listed in the following chart reflect the data collected to date.

Phase II

Objectives	Accomplishments
Demonstrate the validation feature of the SVS System.	The Oxy/Fuel melt system is in a green condition and is supported by strong channel data. The Air/Fuel system is in a yellow condition and the supportind data indicates the beginning of impariment, but it is still validating the reported temperature.
Demonstrate accuracy of the SVS System versus calculated Test Port Temperature (TPT)	After six months in service, both systems are within 4.25 degrees C of the TPT.
Demonstrate repeatability of sensor.	Repeatability was demonstrated to some degree in the Air/Fuel system. However, precise repeatability tests in melter service are not possible due to the absence of a traceable standard. Laboratory testing of systems support repeatability.
Demonstrate the life of the system as compared to Corning's experience with similar configuration and construction sensors in the same location	Both systems are in their 8th month of operation as of 1/15/00.

10.0 Project Objectives and Accomplishments

Project

Objectives	Accomplishments
A more rugged, reliable sensor	Test systems are in their 8th month of service vs. industry average of other Al_2O_3 sensor materials of 3 to 6 months..
Higher quality inner protective sheath	The high purity, high-density material and fabrication processes appear to be providing superior service as of the data of this report. A post mortem analysis will provide more information after the sensors have failed and are removed from service.
Improved data transmission	Data processing speed and responsiveness improved by new electronics. Remote data processing unit reduces data transmission errors and interference. Sensor output and status available in standard digital or 4-20 ma form on twisted pair.
Reduce or eliminate in situ decalibration	Validation system proven under hostile operating conditions.
Improved outer protection sheath	High purity, high density Al_2O_3 material fabricated to AccuTru's specifications has provided the sensor internals protection for more than 8 months vs. industry average of other Al_2O_3 sheath material offering only 3 to 6 months protection.

Target Temperature System Requirements vs. Results To Date.

AccuTru International developed a proposed set of target requirements based on a survey of glass manufacturers. The data collected from this study was used to establish our target objectives for the project.

TARGET REQUIREMENT	ACCOMPLISHMENTS TO DATE
Smart Temperature Monitoring System - Validation	Systems were installed in two of Corning's large continuous melters. One system was installed in an air/fuel melter (named the AF system) and the other in an Oxy/Fuel melter (OF system). Both systems are performing the validation process satisfactorily. The OF system is in green (satisfactory) validation condition and the AF system is in the yellow (or caution) condition. The yellow validation condition indicating a validated signal, but a lower confidence level. This indicates that some component(s) of the sytem have become impaired. Laboratory experiments and controlled in-plant testing of sister systems has proven the high reliability of the validation technology.
Operating range to 1700C	Sister systems to the installed systems tested operationally satisfactory to over 1700C. The White system is operating in the 1650 degree range.
Improved accuracy. Upper operating range +/-0 .5%	Data indicates current output of both systems is +/- .25%. This is supported by data from neighborting sensors. Independent accuracy melt point testing has been conducted by several SVS systems in industrial operation.

TARGET REQUIREMENT	ACCOMPLISHMENTS TO DATE
Repeatability: Upper operating range +/- 0.1%	Data from the cycling of the AF system indicates that repeatability is good, but without independent, traceable standards, we are unable to quantify the precise degree of repeatability. Laboratory testing of lower temperature systems meets the repeatability target. The validation feature of the system keeps the repeatability within the limits of validation parameters.
Lifetime: 8 to 10 years	Materials and fabrication techniques evaluated to date are encouraging. Current test systems have exceeded the expected industry life of 3 to 6 months, using alumina sheaths. Additional efforts in this area are continuing.
Ease of replacement	Both systems were installed with little or no difficulty.
Thermal shock	No thermal shock detected in laboratory testing or insertion into the melters. Additional testing in this area will be required.
Vibration	After six months in service, no mechanical deterioration has been detected in either system.
Common mode noise rejection - 600 VAC	Electrical components are rated at 1500 VAC, 160 dB. In laboratory tests, system electronics tested to greater than 600 VAC.
Electrical leads. 150 feet probe to transmitter, 400 feet transmitter to control room.	Laboratory tests show little or no deterioration in signal with 150 feet and 400 foot cables. Transmitter cable will work to at least 1000 feet.
Transmitter operating temperature limits 70C.	Laboratory tested to 85C.

Transmitter size 5" x 5" x 5"	Current dimensions, including the enclosure are 12" x12" x 6". Smaller version under design
Probe insertion depth (in crown) to 10"	AF & OF systems are inserted 1 to 2 inches in the crown at host's request

11.0 Observations and Conclusions

In summary, the beta test has been satisfactorily completed.

Two SVS Self-validating Sensor Test probes were installed in commercial operation in two separate operations at a selected Corning, Incorporated facility as outlined in the Phase Two test plan.

These two sensors have performed satisfactorily for over 6 months providing validated temperature data and continue to perform well as this report is being written

Output data from the two SVS Test probes compares well with standard sensor probes in the same tanks in close proximity to the test probes.

In one case the SVS Sensor probe in the more severe service appears to have begun to become impaired to a degree that it is indicating a "Warning" condition while still providing validated temperature data.

During the test period some successful improvements to the electronics and the installation setup were made to increase noise rejection and isolation.

All of the objectives of the Phase II Beta Test have been have been achieved or exceeded.

12.0 Commercialization

12.1 Market Demand

The benefits of the self-validating temperature measurement technology (SVS) to the glass industry are discussed in Section 2.3. The Inter-industry applications and benefits are discussed in Section 2.4. As of this writing, several commercial applications of the SVS technology are in service.

12.2 Meeting the Demand

The following are several comments from SVS users that appeared in The Instrument Society of America's July, 1999 *InTech* magazine.

Matt Polhlman, Senior Engineering Specialist, AlliedSignal, Torrance, California

"One self-validating temperature-sensing system has been installed at AlliedSignal's Torrance, Calif. Facility. The new temperature-measurement system solved a major process problem and paid for itself in less than a month."

Dr. Marty Sorensen, Manager, Applied Materials and Technologies Group, Lockheed Martin Idaho Technologies/INEE

"We tested an SVS self-validating temperate sensor, which used advanced contact probe technology, in a laboratory-scale, Joule-heated, refractory lined glass melter. This innovative temperature probe monitors met temperature at any given chamber location and reports to a data acquisition system, providing us with real-time, molten glass temperature. Test results indicate the self-validating sensor probe is more accurate and reliable than classic platinum-rhodium thermocouple and sheathed assemblies used previously. INEEL is planning on using this new technology in our HAW pilot plant."

Don Bruner, Senior Engineering Technician, Corning, Incorporated

"The preliminary results of the Beta tests in our two furnaces are very encouraging. The thermocouples in the melters have been a problem in the glass industry forever. The SVS systems are performing well over the test period and are lasting longer than we had anticipated. The benefits of this technology could be significant."

Gary Carrier, Senior Engineer, DuPont Victoria Operations

"At DuPont's Victoria, Texas facility, operators needed responsive, accurate, and repeatable temperature sensors that could survive a harsh, high-temperature environment. Our incentive for installing the new sensor technology was improved yield and longer catalyst life in a high-value application. Self-validation is another key driver, because knowing if your measurement has been compromised or degraded has tremendous value in our process. Early results.... are very impressive and we are planning to install additional probes to complete our yield improvement program."

Manufacturing

AccuTru is currently assembling and testing all models of its SVS technology at its location in Kingwood, Texas. Several sub-tier suppliers are providing components. AccuTru is considering and entertaining offers to license the manufacturing of SVS to several major instrumentation companies that can meet the anticipated demand. These companies have the proven quality control, manufacturing facilities and technical personnel to economically produce this technology.

Distribution

Presently AccuTru's staff is handling the limited distribution efforts. In order to bring this technology quickly to the glass and other thermochemical industries a well-established distribution system needs to be employed. AccuTru is entertaining offers from several instrumentation companies to market the technology. AccuTru anticipates this system to be operational by first half of 2000.

12.5 Advertising and Promotion

AccuTru will be making formal presentations of this project result to Corning Incorporated and other interested glass companies. AccuTru also plans to present a paper to one or more professional societies and provide an article to several appropriate trade publications. It is anticipated that the marketing arm of the licensee, discussed in 12.4, will present, sell and service the technology in the U.S. glass and other interested industries.

12.6 Future Applications

As this technology continues to prove itself in tough temperature measurement problem areas, the value of validated temperature data is become a real source of economic improvement. Other applications in the glass industry, other than the glass melter, are becoming apparent. Inquiries from other industries are expanding and it is anticipated that by the end of the next decade, self-validating temperature measurement devices will be the standard for most thermochemical industries.

13.0 Summary

This project was initiated to develop a new type of temperature sensor for the glass industry, one of the seven industries identified as heavy users of energy by the Department of Energy. Current energy usage by these industries is approximately 300.0 x 10^{12} BTU's of energy annually. AccuTru International undertook this project in association with the Department of Energy, Corning, Incorporated, Owens-Corning, Anchor Glass Container and Libbey-Owens-Ford.

The initial phase of the project included a definition of the required features for an advanced sensor. These requirements included a more rugged, reliable sensor, a higher quality inner protective sheath, improved data transmission, an improved outer protective sheath, and a method for reducing or eliminating decalibration of the sensor while in service. Further, the companies were looking for improved accuracy, improved repeatability, longer life, and ease of replacement.

Phase I of the project tested and validated the methodology for the self-validation of a sensor while in service. Research on the development of protective sheath material was conducted. However, given the time frame of the project, it was not possible to develop a new protective sheath material. Tests conducted as part of the project determined several candidate materials, which are still under study for further development. Phase II of the project tested the performance of prototype sensors in a typical manufacturing environment.

Laboratory testing shows that the systems tested operated satisfactorily to 1700°C. Data generated by the system indicates that the system's accuracy is in the range of +/- .25%. Because of the limitations of testing in an industrial setting, it was not possible to determine repeatability without independent traceable standards. However, in laboratory testing of the sensors in somewhat lower temperature ranges shows that the systems meet the repeatability requirements within the established parameters.

After completion of bench testing, two sensor systems were fabricated for installation in selected melters at Corning Incorporated. To test the systems in different environments, an oxy/fuel and an air/fuel furnace were selected for the installation. The materials used in the construction of both the inner and outer sheath are commercial alumina protection tubes that were further processed using AccuTru's proprietary technology. It was estimated that the life of the sensors would be approximately three months since the alumina tubes were not covered or coated with platinum.

Both sensors were preheated prior to insertion and showed no thermal shock upon insertion into the melt tank. The sensors were placed on the crown of the tank for approximately 1 hour, then preheated in the top of the port for several minutes before being inserted into the furnace atmosphere. The insertion depth was approximately 2 inches into the furnace atmosphere. Laboratory testing showed no thermal shock failure in sheath materials that were not preheated.

The manufacturing testing identified the need to improve noise rejection for the sensor's electronics. In addition to improving the noise rejection of the electronics units, improvements to the grounding system were made. It should be noted that these systems were installed on a temporary basis, and the wiring was not installed in conduit, nor was the system connected to instrument power and ground. It is possible that some noise introduced into the system was as a result of not having clean power and ground.

The two test sensors were still operating within limits-of-error after ten months of use. One of the sensors is operating in the "green" condition, indicating that it is healthy. The second sensor is operating in the "yellow" condition, showing that there may be some impairment of the sensor but that it is still generating a valid temperature output.

Development of advanced sheath materials is continuing. Commercialization of the technology is moving forward, with installation of systems in multiple glass companies. All of the objectives of both Phase I and the Phase II Beta test have been achieved or exceeded.

14.0 Future Plans

14.1 Project Review Meeting

AccuTru is planning a project review meeting at Corning during January, 2000. Hopefully the group will include representatives of DOE, INEEL, and Corning. We plan to visit each of the companies participating in Phase I individually.

.2 Postmortem of Sensor

At the completion of the test, a postmortem examination of the sensors will be conducted to determine their failure mechanisim and assist in further refinement of the design.

Presentation of Paper

AccuTru plans to present a paper on this project to at least one professional organization in the first quarter of 2000.